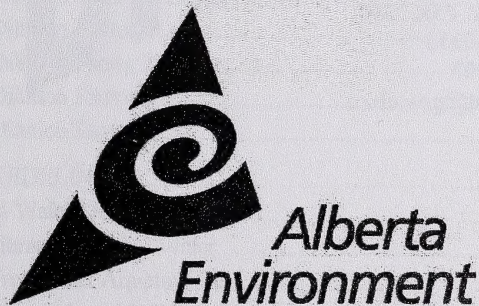


**ALBERTA SOIL AND WATER QUALITY
GUIDELINES FOR HYDROCARBONS
AT UPSTREAM OIL AND GAS FACILITIES**

VOLUME 2: GUIDELINE DEVELOPMENT

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1 INTRODUCTION

The operation of upstream oil and gas facilities can result in the release of hydrocarbon compounds to the environment. This can be a concern either during the operation of the facility, or after decommissioning when land is returned to its former use. Site closure is a term often used to describe regulatory acceptance that decommissioning is complete, and the land is ready to revert to its former or a new use. The *Alberta Soil and Water Quality Guidelines for Upstream Oil and Gas Sites* were developed to assist in environmental management and site closure of upstream oil and gas facilities in Alberta.

The upstream sector of the oil and gas industry includes activities associated with the extraction of oil and gas from the subsurface up to the point it reaches the refinery. Examples of upstream oil and gas facilities include well sites and gas plants. Refineries and facilities for the distribution and sale of refined products are not part of the upstream sector. These guidelines specifically address releases of hydrocarbon mixtures from the upstream sector.

1.1 Guideline Overview and Document Layout

The *Alberta Soil and Water Quality Guidelines for Upstream Oil and Gas Sites* are presented in three volumes:

Volume 1	Protocol;
Volume 2	Guideline Development; and,
Volume 3	User Guidance,

Volume 1 includes an overview of the project, provides background and rationale for the approach used, and develops the technical protocol to be used for guideline development. Volume 2 (this document) provides all chemical-specific information, and illustrates how the protocol developed in Volume 1 was used to develop guidelines. Volume 3 summarizes guideline values, and provides user guidance. Volume 3 provides all the information required by users of generic guidelines. Users wishing to develop modified generic guidelines or site-specific remediation objectives will find useful information in all 3 volumes.

The remainder of the current document (Volume 2) is organized as follows. Section 1.2 summarizes all of the chemical-specific data used in the guideline development process. Section 2 discusses the guideline format. Section 3 provides example calculations for the human health exposure pathways. Section 4 provides example calculations for the ecological health exposure pathways. Section 5 provides examples of the derivation of water quality guidelines. References are included in Section 6.

Volume 3 is the critical document for the application of these guidelines. Certain procedures and conditions described below have limited application as described in Volume 3.

1.2 Sources of Chemical-Specific Information

The protocol document (Volume 1) included values for all non-chemical-specific parameters that are required for guideline development. Chemical-specific parameters for BTEX and B(a)P (benzo(a)pyrene) are summarized in Table 1.1. Chemical-specific parameters for PHC sub-fractions and fractions are summarized in Tables 1.2 and 1.3, respectively. The source of each parameter is indicated in each Table.

2 GUIDELINE FORMAT

The guidelines for BTEX and B(a)P generated in this report, together with the guidelines for the 4 PHC fractions adopted or adapted from CCME (2000), are provided in Tables 2.1 to 2.4 as follows:

- Table 2.1: Alberta Tier 1 Guidelines for Fine Surface Soil;
- Table 2.2: Alberta Tier 1 Guidelines for Coarse Surface Soil;
- Table 2.3: Alberta Guidelines for Fine Subsoil; and,
- Table 2.4: Alberta Guidelines for Coarse Subsoil.

The following points should be noted in conjunction with these tables:

- the lowest value for each chemical and land use in each Table is in bold;
- PHC guidelines that have been adopted without change from CCME (2000) are underlined;
- the guidelines calculated for the protection of potable groundwater, aquatic life, and wildlife watering pathways may not apply at a given site, see user guide for details;
- values exceeding 30,000 mg/kg (the assumed lower limit (CCME, 2000) for formation of residual hydrocarbon) are recorded as "RES"; and,
- all guideline values are rounded to 2 significant figures.

Example calculations are provided in this volume to illustrate the guideline derivation process. Note that the equations in this document follow standard mathematical convention in that multiplication is indicated by two parameters being adjacent with no operator symbol between them. Where this convention might be ambiguous, the multiplication operator (\times) is used explicitly.

2.1 Soil Texture and Depth

The protocols described in Volume 1 were used to generate four tables of soil guidelines (Tables 2.1 to 2.4). Each table presents the soil quality guidelines for a group of chemicals of concern for all pathways and all land uses for one soil texture and depth. Four tables are required to allow for the inclusion of two soil textures (Coarse and Fine) and two soil depths (surface and subsoil).

The guidelines for some pathways apply equally to different soil textures or soil depths. Other guidelines are calculated differently for differing soil textures and/or depths. Further discussion of how guidelines for different soil textures or depths were calculated was included in Volume 1. Some of the calculations used to calculate guidelines for differing soil textures or depths are based on risk management decisions made in CCME (2000) and are discussed in Volume 1.

2.2 Incorporating Canada-Wide Standard Hydrocarbon Guidelines

The Canada-Wide Standard for Petroleum Hydrocarbons (CCME, 2000) developed generic levels for four hydrocarbon fractions, F1 to F4, and four land uses. Where appropriate, these generic levels are used without modification as guidelines in the current work. However, for groundwater pathways (protection of human, livestock, and wildlife drinking water and freshwater aquatic life) the guidelines are recalculated to reflect the Alberta-specific recharge values of 0.060 m/year and 0.012 m/year for Coarse and Fine soils, respectively. In addition, guidelines are calculated for natural area land use, which is within the scope of the current work, but outside the scope of the PHC Canada-Wide Standard. Based on the scenario described in Volume 1, guidelines for natural areas are calculated using the same equations as for agricultural land use with two changes: i) the human soil ingestion, soil dermal contact, and indoor vapour inhalation pathways are excluded; and, ii) a deer is substituted for a dairy cow as the livestock/wildlife receptor for the soil ingestion and protection of groundwater for livestock/wildlife watering pathways.

2.3 Water Quality Guidelines

Two types of water quality guidelines are used in the current work. Exposure point water quality guidelines are the limiting concentrations in water to which a receptor is actually exposed. These guidelines are used as water quality targets for the protection of groundwater pathways. Groundwater guidelines are used to assess what concentrations of contaminants are acceptable in groundwater. Water quality guidelines are compiled or calculated in Section 5 for BTEX, F1, and F2 for human drinking water, protection of freshwater aquatic life, and livestock and wildlife watering.

2.4 Non Toxicity-Based Considerations

In addition to the toxic risks addressed by receptor/pathway analyses, certain other management considerations apply. Chief among these are:

- ignition hazard;
- odour and appearance; and,
- formation of non-aqueous phase liquids (NAPL).

Whereas the primary focus in this project is prevention of toxic effects to human and ecological receptors, in certain situations these pathways may be of little immediate concern and contaminant management is driven by consideration of policy factors (CCME, 2000). Aesthetics and avoidance of free product considerations were incorporated as policy factors in the development of the PHC Canada-Wide Standard (CCME, 2000). Many of the same policy decisions are adopted in this document. In particular, removal of free product will normally be a requirement of any remedial action plan.

One issue that required further discussion is ignition hazard. The lower explosive limits (LELs) is a measure of the minimum concentration of a compound in air that will burn in air when a source of ignition is present. Hydrocarbon LEL values are well documented, and, for most compounds, are close to 10,000 parts per million by volume (ppmv). It is more difficult to determine what hydrocarbon soil concentration presents a risk of fire or explosion. The worst possible case would be a closed volume of air in equilibrium with hydrocarbon contaminated soil. However, in reality, it is likely that air movement and volatilization kinetics will always ensure that actual concentrations in air are well below the worst case scenario.

Initial calculations show that BTEX concentrations at or below the soil quality guidelines calculated in this document would not result in vapour concentrations above 20% of LEL even in the worst case scenario. It is unlikely, therefore, that ignition hazard will be a significant consideration in setting BTEX soil quality guidelines.

It is not so clear whether ignition hazard should be considered when setting soil quality guidelines for the volatile PHC fractions. However, this issue was not addressed in the PHC Canada-Wide Standard (CCME, 2000), and so, for consistency, no attempt will be made to address it here. It is recommended, however, that this issue be given careful consideration when the time comes for a review of the PHC Canada-Wide Standard.

Based on the above discussion, no corrections were made to the guidelines calculated in this project to account for ignition hazard.

3 HUMAN HEALTH SOIL QUALITY GUIDELINES

This section discusses the human health toxicological exposure limits for the chemicals of concern and describes the development of guidelines for the human health pathways for BTEX, B(a)P, and PHC fractions F1 to F4. The human health guidelines were developed based on exposure to an adult

receptor for the carcinogenic chemicals (*i.e.*, benzene and B(a)P). For the non-carcinogenic chemicals (*i.e.*, toluene, ethylbenzene and xylenes and PHC fractions F1 to F4), exposure to an adult receptor was considered in the industrial scenario, and exposure to a child receptor (aged 7 months to 4 years) in the agricultural, residential, and commercial scenarios.

Example calculations are provided, using toluene as the chemical of concern, and a residential scenario for each of the human health pathways examined (*i.e.*, soil ingestion, soil dermal contact, indoor vapour inhalation, and ingestion of contaminated groundwater). Where applicable, separate calculations are provided for Coarse and Fine soils. In addition, the soil ingestion guideline is calculated for benzene to provide an example of a guideline calculation for a carcinogenic compound.

3.1 Human Exposure Limits

The human health soil quality guidelines developed in the following sections are based on a human health exposure limit, which reflects the dose or concentration of the chemical of concern that is considered unlikely to cause adverse health effects in sensitive humans. The exposure limits for BTEX and B(a)P are included in Table 1.1. The exposure limits for the PHC sub-fractions are included in Table 1.2. The source of each exposure limit is included as a footnote with the applicable table. The approach taken to develop the exposure limits for the chemicals of concern was to use regulatory-approved limits, where available, in the following order of preference:

- Health Canada (Health Canada, 1996a);
- United States Environmental Protection Agency IRIS database (US EPA, 2001); and,
- Canada-Wide Standards for PHC in Soil (CCME, 2000).

Benzene and B(a)P are classified as carcinogens by Health Canada (1996a). Toluene, ethylbenzene, xylenes and all four PHC fractions are classified as non-carcinogens. For the carcinogens, risk-specific doses (RsD) or risk-specific concentrations (RsC) were developed such that exposure to the chemicals of concern would not result in an incremental cancer risk of more than 1 in 100,000 (*i.e.*, 1×10^{-5}) above background incidence.

For the non-carcinogens, regulatory limits for oral or inhalation exposure were used directly as the tolerable daily intake (TDI) or reference concentration (RC).

3.2 Accounting for Background Exposure

Background exposure was addressed in two ways. Firstly, the possibility of receptors being exposed to levels of hydrocarbon contamination in background soils was considered, and included in the equations provided in Volume 1 to calculate human pathways. However, the background level of all the chemicals of concern considered in this project is assumed to be 0.

Secondly, it is recognized (CCME, 1996) that exposure to the chemicals of concern can occur via other media than soil (*e.g.*, water, air, food, and consumer products). Accordingly, the soil quality guidelines incorporated a soil allocation factor (SAF), that was used to determine what fraction of the total acceptable exposure was allocated to exposure via contaminated soil. SAF values for BTEX were taken from the SAF for hydrocarbon fraction F1 (CCME, 2000). The value for BaP was taken from the SAF for hydrocarbon fraction F3 (CCME, 2000). SAF values are summarized in Tables 1.1 and 1.3.

3.3 Soil Ingestion

The soil quality guidelines calculated for the soil ingestion pathway (SQG_{SI}) are presented in Tables 2.1 to 2.4. The guidelines for PHC fractions F1 to F4 were adopted from the generic levels in CCME (2000) without change. The following equation was used to calculate the SQG_{SI} . Data for toluene in a residential land use scenario are provided as an example:

$$SQG_{SI} = \frac{(TDI - EDI) \times SAF \times BW \times 10^3}{SIR \times AF_G \times ET} + [BSC]$$

Where:	SQG_{SI}	=	human health soil quality guideline for soil ingestion (mg/kg);
	TDI	=	tolerable daily intake (0.22 mg/kg-bw/day; see Table 1.1);
	EDI	=	estimated daily intake (0.0028 mg/kg-bw/day; see Table 1.1);
	SAF	=	soil allocation factor (0.5; see Table 1.1);
	BW	=	toddler body weight (16.5 kg; see Volume 1 Table 2.4);
	10^3	=	conversion factor from kg to g;
	SIR	=	soil ingestion rate for the toddler (0.08 g/day; see Volume 1 Table 2.4);
	AF_G	=	absorption factor for gut (1; see Table 1.1);
	ET	=	exposure term for residential use (1; see Volume 1 Table 2.4); and,
	BSC	=	background soil concentration (0 mg/kg; see Table 1.1).

Substituting these values in the above equations and rounding to 2 significant figures yields a value of 22,000 mg/kg, which is the guideline for incidental human soil ingestion for toluene in a residential setting (SQG_{SI}) (Tables 2.1 and 2.2).

3.4 Soil Dermal Contact

The soil quality guidelines calculated for the soil dermal contact pathway (SQG_{DC}) are presented in Tables 2.1 to 2.4. The guidelines for PHC fractions F1 to F4 were adopted from the generic levels in CCME (2000) without change. The following equation was used to calculate the SQG_{DC} . Data for toluene in a residential land use scenario are provided as an example:

$$SQG_{DC} = \frac{(TDI - EDI) \times SAF \times BW \times 10^6}{AF_D \times \{ (SA_{HANDS} \times DL_{HANDS}) + (SA_{OTHER} \times DL_{OTHER}) \} \times EF \times ET} + [BSC]$$

Where:	SQG_{DC} =	human health soil quality guideline for soil dermal contact (mg/kg);
	TDI =	tolerable daily intake (0.22 mg/kg-bw/day; see Table 1.1);
	EDI =	estimated daily intake (0.0028 mg/kg-bw/day; see Table 1.1);
	SAF =	soil allocation factor (0.5; see Table 1.1);
	BW =	toddler body weight (16.5 kg; see Volume 1 Table 2.4);
	10^6 =	conversion factor from kg to mg;
	AF_D =	absorption factor for soil dermal contact (0.12; see Table 1.1);
	SA_{hands} =	toddler hand surface area (430 cm ² ; see Volume 1 Table 2.4);
	DL_{hands} =	dermal soil loading for a toddler's hands (0.1 mg/cm ² -event; see Volume 1 Table 2.4);
	SA_{other} =	surface area for other exposed skin (2,580 cm ² ; see Volume 1 Table 2.4);
	DL_{other} =	dermal soil loading for other exposed skin (0.01 mg/cm ² -event; see Volume 1 Table 2.4);
	EF =	exposure frequency (1 event/day; see Volume 1 Table 2.4)
	ET =	exposure term for residential use (1, see Volume 1 Table 2.4); and,
	BSC =	background soil concentration (0 mg/kg; see Table 1.1).

Substituting these values in the above equations and rounding to 2 significant figures yields a value of 220,000 mg/kg. This value is greater than the assumed lower limit of 30,000 mg/kg for residual hydrocarbon formation, and so the guideline for human soil dermal contact for toluene in Coarse soil (SQG_{S1}) is reported in Table 2.2 as "RES".

3.5 Indoor Vapour Inhalation

The soil quality guidelines calculated for the indoor vapour inhalation pathway (SQG_{II}) are presented in Tables 2.1 to 2.4. The guidelines for PHC fractions F1 to F4 were adopted from the generic levels in CCME (2000) without change. An SQG_{II} was not calculated for B(a)P because B(a)P is not volatile, and thus would not have an appreciable indoor air concentration. The following equation was used to calculate the SQG_{II} . Data for toluene in the residential land use scenario for both Coarse and Fine surface soil in a house with a basement, are provided as examples:

$$SQG_{II} = \frac{(RfC - C_a) \times [\theta_w + (K_{oc} \times f_{oc} \times \rho_b) + (H' \times \theta_a)] \times SAF \times DF_i \times 10^3}{H' \times \rho_b \times ET \times 10^6} + BSC$$

Where:	SQG_{II}	=	soil quality guideline for indoor infiltration (mg/kg);
	RfC	=	reference concentration (3.8 mg/m ³ ; see Table 1.1);
	C_a	=	background indoor air concentration (0.005 mg/m ³ ; see Table 1.1);
	θ_w	=	moisture-filled porosity (0.119 (Coarse soil) or 0.168 (Fine-texture soil); see Volume 1 Table 2.1);
	K_{oc}	=	organic carbon partition coefficient (234 mL/g; see Table 1.1);
	f_{oc}	=	fraction organic carbon (0.005 g/g; see Volume 1 Table 2.1);
	ρ_b	=	dry soil bulk density (1.7 g/cm ³ (Coarse soil) or 1.4 g/cm ³ (Fine soil); see Volume 1 Table 2.1);
	H'	=	dimensionless Henry's Law Constant (0.274; see Table 1.1);
	θ_a	=	vapour-filled porosity (0.281 (Coarse soil) or 0.132 (Fine soil); see Volume 1 Table 2.1);
	SAF	=	soil allocation factor (0.5; see Table 1.1);
	DF_i	=	dilution factor from soil gas to indoor air (22,500 (Coarse soil) or 509,000 (Fine soil); see derivation below);
	10^3	=	conversion factor from kg to g;
	ET	=	exposure term for residential (1; see Volume 1 Table 2.4);
	10^6	=	conversion factor from m ³ to cm ³ ; and,
	BSC	=	background soil concentration (0 mg/kg; see Table 1.1).

Substituting these values in the above equations and rounding to 2 significant figures yields values of 4,600 mg/kg (Fine soil) and 200 mg/kg (Coarse soil) which are the guidelines for human indoor vapour inhalation of toluene in a residential scenario in a building with a basement (SQG_{II}) (Tables 2.1 and 2.2, respectively).

The dilution factor (DF_i) was calculated as follows:

$$DF_i = \frac{1}{\alpha}$$

Where:	DF_i	=	dilution factor from soil gas concentration to indoor air concentration (unitless); and,
	α	=	attenuation coefficient (unitless; see derivation below).

3.5.1 Calculation of α for Coarse Soils

The attenuation coefficient for Coarse soils was calculated using the following equation:

$$\alpha = \frac{\left(\frac{D_T^{eff} A_B}{Q_B L_T} \right)}{\left(\frac{D_T^{eff} A_B}{Q_{soil} L_T} \right) + 1}$$

Where: α = attenuation coefficient (unitless);
 D_T^{eff} = effective porous media diffusion coefficient (0.00790 cm²/s; see derivation below);
 A_B = building area (2,700,000 cm²; see derivation below);
 Q_B = building ventilation rate (203,000 cm³/s; see derivation below);
 L_T = distance from contaminant source to foundation (30 cm; see Volume 1 Table 3.1); and,
 Q_{soil} = volumetric flow rate of soil gas into the building (9.14 cm³/s; see derivation below).

Substituting these values in the above equations yields a value for α of 4.44x10⁻⁵, corresponding to a dilution factor of 22,500.

Calculation of D_T^{eff} :

$$D_T^{eff} \approx D_a \times \left(\frac{\theta_a^{10/3}}{\theta_t^2} \right)$$

Where: D_T^{eff} = overall effective porous media diffusion coefficient based on vapour-phase concentrations for the region between the source and foundation (cm²/s);
 D_a = diffusion coefficient in air (0.087 cm²/s; see Table 1.1);
 θ_a = soil vapour-filled porosity (0.281; see Volume 1 Table 2.1); and,
 θ_t = soil total porosity (0.4; see Volume 1 Table 2.1).

Substituting these values in the above equations yields a value for D_T^{eff} of 0.00790 cm²/s.

Calculation of A_B :

A_B is the entire below ground surface area of the building, *i.e.*, the footprint area plus the area of walls below ground, and is calculated as follows:

$$A_B = (L_B W_B) + 2Z_{crack} (L_B + W_B)$$

Where: A_B = below ground building area (cm²);
 L_B = building length (1,225 cm; see Volume 1 Table 3.1);
 W_B = building width (1,225 cm; see Volume 1 Table 3.1); and,
 Z_{crack} = distance below ground to idealized cylinder (i.e., basement depth below ground; 244 cm; see Volume 1 Table 3.1).

Substituting these values in the above equations yields a value for A_B of 2,700,000 cm².

Calculation of Q_B :

$$Q_B = \frac{L_B W_B H_B ACH}{3,600}$$

Where: Q_B = building ventilation rate (cm³/s);
 L_B = building length (1,225 cm; see Volume 1 Table 3.1);
 W_B = building width (1,225 cm; see Volume 1 Table 3.1);
 H_B = building height, including basement (488 cm; see Volume 1 Table 3.1);
ACH = air exchanges per hour (1 h⁻¹; see Volume 1 Table 3.1); and,
3,600 = conversion factor from hours to seconds.

Substituting these values in the above equations yields a value for Q_B of 203,000 cm³.

Calculation of Q_{soil} :

$$Q_{\text{soil}} = \frac{2\pi\Delta P k_v X_{\text{crack}}}{\mu \ln \left[\frac{2Z_{\text{crack}}}{r_{\text{crack}}} \right]}$$

Where: Q_{soil} = volumetric flow rate of soil gas into the building (cm³/s);
 ΔP = pressure differential (40 g/cm·s²; see Volume 1 Table 3.1);
 k_v = soil vapour permeability to vapour flow (1.0 x 10⁻⁸ cm²; see Volume 1 Table 2.1);
 X_{crack} = length of idealized cylinder (4,900 cm; see Volume 1 Table 3.1);
 μ = vapour viscosity (0.000173 g/cm·s; see Volume 1 Table 3.1);
 Z_{crack} = distance below grade to idealized cylinder (244 cm; see Volume 1 Table 3.1); and,
 r_{crack} = radius of idealized cylinder (0.203 cm; see Volume 1 Table 3.1).

Substituting these values in the above equations yields a value for Q_{soil} of 9.14 cm³/s.

3.5.2 Calculation of α for Fine Soils

The attenuation coefficient for Fine soils was calculated using the following equation:

$$\alpha = \frac{\left(\frac{D_T^{eff} A_B}{Q_B L_T} \right)}{1 + \left(\frac{D_T^{eff} A_B}{Q_B L_T} \right) + \left(\frac{D_T^{eff} A_B L_{crack}}{D_{crack} A_{crack} L_T} \right)}$$

Where:

- α = attenuation coefficient (unitless);
- D_T^{eff} = effective porous media diffusion coefficient (0.00113 cm²/s; see derivation below);
- A_B = building area (2,700,000 cm²; see derivation above for Coarse soil);
- Q_B = building ventilation rate (203,000 cm³/s; see derivation above for Coarse soil);
- L_T = distance from contaminant source to foundation (30 cm; see Volume 1 Table 3.1);
- L_{crack} = thickness of the foundation (11.25 cm; see Volume 1 Table 3.1);
- D_{crack} = effective vapour-pressure diffusion coefficient through the crack (0.00454 cm²/s; see Volume 1 Table 3.1); and,
- A_{crack} = area of cracks through which contaminant vapours enter building (995 cm²; see Volume 1 Table 3.1).

Substituting these values in the above equations yields a value for α of 1.97×10^{-6} , corresponding to a dilution factor of 509,000.

Calculation of D_T^{eff} :

$$D_T^{eff} = D_a \times \left(\frac{\theta_a^{1/3}}{\theta_t} \right)$$

Where:

- D_T^{eff} = overall effective porous media diffusion coefficient based on vapour-phase concentrations for the region between the source and foundation (cm²/s);
- D_a = diffusion coefficient in air (0.087 cm²/s; see Table 1.1);
- θ_a = soil vapour filled porosity (0.132; see Volume 1 Table 2.1); and,
- θ_t = soil total porosity (0.3; see Volume 1 Table 2.1).

Substituting these values in the above equations yields a value for D_T^{eff} of 0.00113 cm²/s.

3.6 Protection of Potable Groundwater

The soil quality guidelines calculated for the protection of potable groundwater pathway (SQ_{GW}) are presented in Tables 2.1 to 2.4.

3.6.1 PHC Fractions F1 and F2

The SQ_{GW} for PHC fractions F1 and F2 are recalculated from the Canada-Wide Standard values by substituting the Alberta-specific recharge value (0.060 m/year and 0.012 m/year for Coarse and Fine soils, respectively) in the Canada-Wide Standard algorithm.

Calculation of Guideline for Sub-Fraction

Data for the aromatic C_{>8}-C₁₀ sub-fraction of fraction F1 in the residential land use scenario for Coarse soil is provided below as an example:

$$SQ_{GWi} = \frac{(TDI - EDI) \times (K_d + (\theta_m / \rho_w)) \times BW \times DF_w}{IR_w} + BSC$$

Where:	SQ _{GWi} =	soil quality guideline for protection of potable groundwater for sub-fraction “i” (in this case “i” is the aromatic C _{>8} -C ₁₀ sub-fraction; mg/kg);
	TDI	= tolerable daily intake for aromatic C _{>8} -C ₁₀ sub-fraction (0.04 mg/kg-bw/day; see Table 1.2);
	EDI	= estimated daily intake aromatic C _{>8} -C ₁₀ sub-fraction (0.00938 mg/kg-bw/day; see Table 1.2);
	K _d	= distribution coefficient (7.9 mL/g; K _{oc} (1,580 mL/g) x f _{oc} (0.005); see Table 1.2 and Volume 1 Table 2.1);
	θ _m	= ratio of mass of water in soil/dry mass of soil (0.07 g/g; see Volume 1 Table 2.1);
	ρ _w	= density of water (1.0 g/cm ³ ; see Volume 1 Table 3.2);
	BW	= toddler body weight (16.5 kg; see Volume 1 Table 2.4);
	DF _w	= groundwater/pore water dilution factor (54.3 for Coarse soils; see derivation below);
	IR _w	= ingestion rate of water for toddler (0.6 L/day; see Volume 1 Table 2.4); and,
	BSC	= background soil concentration (0 mg/kg; see Table 1.1).

Substituting these values in the above equations and rounding to 3 significant figures yields a value of 366 mg/kg which is the guideline for protection of potable groundwater in Coarse soil for the aromatic C_{>8}-C₁₀ sub-fraction (SQG_{GW}).

The above calculation for the aromatic C_{>8}-C₁₀ sub-fraction, and similar calculations for the other F1 sub-fractions yield values (SQG_{GW*i*}) that are tabulated below, together with the assumed proportion of each fraction (F_i):

<i>Sub-Fraction</i>	<i>SQG_{GW<i>i</i>} (mg/kg)</i>	<i>F_i</i>
aliphatic C _{>6} -C ₈	149,000	0.55
aliphatic C _{>8} -C ₁₀	21,200	0.36
aromatic C _{>8} -C ₁₀	366	0.09

The overall SQG_{GW} for F1 is then calculated by using the following formula:

$$SQG_{GW} (mg / kg - bw / day) = \frac{1}{\sum_i \frac{F_i}{SQG_{GW_i}}}$$

where:

- SQG_{GW} = soil quality guideline for protection of potable groundwater (mg/kg);
F_i = the assumed proportion of the fraction made up of sub-fraction i (dimensionless; see Table 1.2); and,
SQG_{GW*i*} = soil quality guideline for protection of potable groundwater for sub-fraction "i" (mg/kg).

Substituting the above values in this equation and rounding to 2 significant figures yields a value of 3,700 mg/kg which is the guideline for protection of potable groundwater in Coarse soil for PHC fraction F1 (SQG_{GW}), Table 2.2.

Calculation of Dilution Factor

The dilution factor was calculated as follows:

$$DF_w = \frac{BK_i}{IL} + 1$$

- Where: DF_w = groundwater/pore water dilution factor (unitless);
B = effective mixing depth in aquifer (2 m; see Volume 1 Table 3.2);
K = saturated hydraulic conductivity of aquifer (320 m/y (Coarse soil) or 32 m/y (Fine soil); see Volume 1 Table 2.1);
i = hydraulic gradient (0.05 ; see Volume 1 Table 3.2);

- I = infiltration (recharge) rate (0.060 m/y for Coarse soil or 0.012 m/y for Fine soil; see Volume 1 Table 2.1); and,
L = site length (10 m; see Volume 1 Table 3.2).

Substituting these values in the above equations yields values for the dilution factor of 54.3 (Coarse soil) and 27.7 (Fine soil).

3.6.2 BTEX Compounds

The SQG_{GW} for the BTEX compounds are calculated using the same formula as for F1 and F2, adapted to use the Canadian Drinking Water Quality Guidelines (Health Canada, 1996b) as the toxicological basis, rather than the TDI. Data for toluene in the residential land use scenario for Coarse soil are provided below as an example:

$$SQG_{GW} = C_{DW} (K_d + (\theta_m / \rho_w)) DF_w + BSC$$

- Where:
- SQG_{GW} = soil quality guideline for protection of potable groundwater (mg/kg);
 - C_{DW} = drinking water quality guideline (0.024 mg/L; Table 5.1);
 - K_d = chemical-specific distribution coefficient (1.17 mL/g; K_{oc} (234 mL/g) x f_{oc} (0.005); see Table 1.1 and Volume 1 Table 2.1);
 - θ_m = ratio of mass of water in soil/dry mass of soil (0.07 g/g; see Volume 1 Table 2.1);
 - ρ_w = density of water (1.0 g/cm³; see Volume 1 Table 3.2);
 - DF_w = groundwater/pore water dilution factor (54.3; see derivation in Section 3.6.2 above);
 - BSC = background soil concentration (0 mg/kg; see Table 1.1).

Substituting these values in the above equations and rounding to 2 significant figures yields a value of 0.86 mg/kg which is the guideline for protection of potable groundwater in Coarse soil for toluene (SQG_{GW}).

3.6.3 PHC Fractions F3 and F4, and B(a)P

No guidelines for these groups or compounds are calculated for these pathways based on their extremely limited aqueous solubility and subsurface mobility.

3.6.4 Minimum Till Thickness

At some sites, a sufficient thickness of till may be present between contaminated soil and an underlying domestic use aquifer (DUA), such that contaminant concentrations in the DUA are not expected to

exceed respective drinking water quality guidelines. In such cases, the guideline for the protection of groundwater for drinking water pathway need not be applied. Based on a screening level calculation, the minimum thickness of saturated Fine material, with a measured bulk hydraulic conductivity of 10^{-7} m/s or less ($K < 10^{-7}$ m/s), required to exclude this pathway is 5 m. The calculations below explain how this thickness was determined.

The calculation was based on the following assumptions:

- it was assumed as a worst case that hydrocarbon compounds were each present in pore water at the contaminant source at their respective solubilities;
- dissolved hydrocarbon components are assumed to travel downwards through till underlying the contaminant source;
- hydrocarbon concentrations are assumed to decrease due to biodegradation at the rates used in the ecological groundwater model (Section 4.3); and,
- upon reaching the DUA, it is assumed that there is dilution due to mixing as calculated in Section 3.6.1 above.

The above assumptions were used to calculate the minimum thickness of till (L_{min}) required to ensure that concentrations of each of the hydrocarbon chemicals of concern do not exceed drinking water guidelines in the DUA using the following equation. The calculation for benzene (the most mobile of the hydrocarbon compounds) is provided as an example:

$$L_{min} = \frac{\text{Log}(S/DWQG \times DF)}{\text{Log}(2)} \times \frac{Kit_{1/2}}{R\theta}$$

Where:	L_{min}	=	minimum till thickness as defined above;
	Log	=	logarithm operator (base 10);
	S	=	solubility of compound (1,780 mg/L for benzene; Table 1.1);
	DWQG	=	drinking water quality guideline for component (0.005 mg/L for benzene; Table 5.1);
	DF	=	dilution factor for pore water/aquifer mixing, Fine soil (27.7; calculated in Section 3.6.1. above);
	K	=	saturated vertical hydraulic conductivity in till (3.15 m/year, based on an assumed hydraulic conductivity of 10^{-7} m/s);
	i	=	vertical hydraulic gradient in saturated till (0.1; assumed reasonable worst case);
	$t_{1/2}$	=	half life of compound (1 year for benzene, Table 1.1);
	R_s	=	retardation factor in saturated zone (2.89; calculated below); and,
	θ_t	=	total porosity for Fine soil (0.3; see Volume 1, Table 2.1).

Substituting these values for benzene in the above equation, and rounding to the nearest meter, yields a value for the minimum till thickness of 5 m, using benzene as an example. Performing this calculation for other hydrocarbon compounds shows that benzene is the limiting compound, and accordingly 5 m is adopted as the minimum thickness of Fine material ($K < 10^{-7}$ m/s) required to exclude the protection of groundwater for drinking water pathway.

It should be noted that this calculation contains many conservative assumptions. In particular the requirement is that the measured bulk hydraulic conductivity of the material is less than 10^{-7} m/s. Commonly-used methods of measuring bulk hydraulic conductivity in the field (e.g., rising head test) measure *horizontal* hydraulic conductivity. The above calculations are based on *vertical* hydraulic conductivity. Vertical hydraulic conductivities are often assumed to be an order of magnitude lower than horizontal values in sedimentary materials such as till, and so significant conservatism is introduced into this screening level calculation.

Retardation Factor

The retardation factor is calculated using the following equation:

$$R_s = 1 + \frac{\rho_b K_{oc} f_{oc}}{\theta_t}$$

where:

R_s	=	retardation factor in saturated zone;
ρ_b	=	dry soil bulk density (Fine soil: 1.4 g/cm ³ ; see Volume 1 Table 2.1);
K_{oc}	=	organic carbon partition coefficient (81.2 mL/g; see Table 1.1);
f_{oc}	=	fraction organic carbon (0.005 g/g; see Volume 1 Table 2.1); and,
θ_t	=	total soil porosity (Fine soil: 0.30; see Volume 1 Table 2.1).

Substituting these values in the above equations yields a value for the retardation factor for benzene in Fine soil of 2.89.

3.7 Example Calculation for Carcinogenic Chemicals

Guidelines for carcinogenic chemicals (benzene and B(a)P) are calculated in a similar way to those for non-carcinogenic chemicals with the following differences:

- the risk-specific concentration (RsC), evaluated at an incremental cancer risk of 1 in 100,000, is used in place of the reference concentration (RfC);
- the risk-specific dose (RsD), evaluated at an incremental cancer risk of 1 in 100,000, is used in place of the tolerable daily intake (TDI);

- background exposure is not considered, as guidelines are based on incremental cancer risk above background;
- exposure to carcinogens is evaluated for lifetime exposure (CCME, 1996); and,
- adults, rather than toddlers, are used as the receptor of concern in all land uses.

The soil quality guidelines calculated for benzene for the soil ingestion pathway (SQG_{SI}) are presented in Tables 2.1 to 2.4. The following equation was used to calculate the SQG_{SI} . Data for benzene in a residential land use scenario are provided as an example:

$$SQG_{SI} = \frac{RsD \times SAF \times BW \times 10^3}{SIR \times AF_G \times ET}$$

Where:	SQG_{SI}	=	human health soil quality guideline for soil ingestion (mg/kg);
	RsD	=	risk-specific dose evaluated at an incremental cancer risk of 1 in 100,000 (0.00069 mg/kg-bw/day; see Table 1.1);
	SAF	=	soil allocation factor (0.5; see Table 1.1);
	BW	=	adult body weight (70.7 kg; see Volume 1 Table 2.4);
	10^3	=	conversion factor from kg to g;
	SIR	=	soil ingestion rate for the adult (0.02 g/day; see Volume 1 Table 2.4);
	AF_G	=	absorption factor for gut (1; see Table 1.1); and,
	ET	=	exposure term for residential use (1; see Volume 1 Table 2.4).

Substituting these values in the above equations and rounding to 2 significant figures yields a value of 1,200 mg/kg, which is the guideline for incidental human soil ingestion for benzene in a residential setting (SQG_{SI}) (Tables 2.1 and 2.2).

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4 ECOLOGICAL HEALTH GUIDELINES

This section describes the development of ecological health guidelines for BTEX, B(a)P, and PHC fractions F1 to F4, and provides example calculations for each of the ecological health pathways examined (*i.e.*, plant/invertebrate soil contact, soil ingestion by livestock/wildlife, protection of groundwater for aquatic life, and protection of groundwater for livestock/wildlife ingestion), where applicable. Where required, ecological exposure limits were derived for this project. Details are provided in Appendix 1.

4.1 Plant/Invertebrate Soil Contact

The soil quality guidelines calculated for the plant/invertebrate soil contact pathway (SQG_{SC}) are presented in Tables 2.1 to 2.4. SQG_{SC} for PHC fractions F1 to F4 are adopted without change from CCME (2000).

Plant, invertebrate, and micro-organism toxicity data exist for BTEX, and are summarized in Appendix I. However, significant advances have been made in the last few years in the techniques for determining the toxicity of highly volatile compounds, and a new set of protocols is available (Environment Canada, 1998a,b,c). It is not clear whether existing data are acceptable based on the Environment Canada guidelines. Accordingly, none of the existing data were used in the guideline derivation process.

A new study was commissioned for this report. The purpose of the study was to determine the toxicity of BTEX compounds to one terrestrial plant species and one earthworm species, using up to date protocols for toxicity tests with volatile compounds. A single plant species was considered acceptable for this work, because the species chosen was the most sensitive species in work done for the petroleum hydrocarbon Canada-Wide Standard (CCME, 2000). The study was undertaken by ESG International (ESG, 2001), with the following scope:

- the test species were *Eisenia andrei* (earthworm) and *Agropyron dasystachyum* (early northern wheatgrass);
- earthworm tests measured 7 and 14 day mortality endpoints;
- wheatgrass tests measured seedling emergence, shoot and root length and dry and wet biomass endpoints, all at 14 days;
- Two soils were used: "Artificial Soil" was a Coarse soil; and "Alberta Till" was a Fine soil;
- procedures were adopted to minimize loss of volatile compounds from the tests; and,
- chemical analysis was undertaken at the start of the tests to estimate the actual concentrations of BTEX compounds to which the organisms were exposed at the start of the tests.

A summary of the results of this study can be found in Appendix I. The derivation of the soil quality guideline for plant/invertebrate soil contact (SQG_{SC}) followed the procedure developed for other hydrocarbon compounds in the PHC CWS (CCME, 2000). This procedure is as follows:

- for each distinct test/endpoint, only the data representing a 50% effect are considered (*i.e.*, median lethal concentration (LC50) or 50% inhibition concentration (IC50));
- if tests differ only in duration, only data for the longest duration are used;
- if multiple data are available for the same chemical, endpoint and species, these data are replaced by their geometric mean;
- for natural area, agricultural, or residential land use, the SQG_{SC} was calculated as the 25th percentile of plant and invertebrate data; and,
- for commercial and industrial land use, the SQG_{SC} was calculated as the 50th percentile of plant data only.

SQG_{SC} surface soil values are calculated using the above procedure and are provided in Tables 2.1 and 2.2. SQG_{SC} values for subsoil are calculated based on management decisions in the PHC CWS (CCME, 2000). In the PHC CWS, subsoil guidelines were between 2 and 6 times greater than the surface soil guidelines, based on the lower biological activity levels at subsoil depths, but also taking into account other considerations such as aesthetics, safety, and underground infrastructure. In this document, subsoil guidelines for this pathway are calculated by doubling the corresponding surface soil guideline, except in cases where this would result in a concentration close to the solubility of the compound in question, in which case the corresponding surface soil guideline was adopted directly as the subsoil guideline. Subsoil guidelines are summarized in Tables 2.3 and 2.4.

4.2 Soil Ingestion by Livestock/Wildlife

The calculated soil quality guidelines for the soil ingestion by livestock/wildlife pathway (SQG_{ESI}) are presented in Tables 2.1 to 2.4. DTEDs for livestock and wildlife were developed for BTEX in Appendix 1, and are summarized in Table 1.1. DTEDs for the four hydrocarbon fractions F1 to F4 were adopted directly from CCME (2000). The SQG_{ESI} were developed based on exposure to a dairy cow in the agricultural land use scenario and to a mule deer in the natural area land use scenario. A soil quality guideline was not developed for B(a)P because carcinogenic endpoints are not normally considered relevant in ecological risk assessment, and the non-carcinogenic toxicity of B(a)P was accounted for in the soil quality guideline derived for PHC fraction F3 (CCME, 2000).

The SQG_{ESI} was calculated using the following equation. Data for ethylbenzene in the natural area land use scenario is provided as an example:

$$SQG_{ESI} = \frac{0.75 \times DTED \times BW \times 1,000}{SIR \times BF}$$

Where: SQG_{ESI} = ecological quality guideline for soil ingestion livestock/wildlife (mg/kg);
0.75 = factor to prevent animals from being exposed to more than 75% of the DTED (unitless; CCME, 1996);

DTED =	daily threshold effect dose for livestock/wildlife (2.91 mg/kg-bw/day; see Table 1.1, and Appendix I);
BW =	body weight for deer (68 kg; see Volume 1 Table 2.5);
1,000 =	conversion factor from kg to g;
SIR =	soil ingestion rate for deer (44 g/day; see Volume 1 Table 2.5); and,
BF =	bioavailability factor (1; assumed).

Substituting these values in the above equation and rounding to 2 significant figures yields a value of 3,400 mg/kg, which is the guideline for soil ingestion by wildlife (SQG_{ESL} ; Tables 2.1 and 2.2).

4.3 Protection of Groundwater for Ecological Receptors

The soil quality guidelines calculated for protection of groundwater for aquatic life (SQG_{AL}), and for the protection of groundwater for livestock/wildlife watering (SQG_{GI}) were calculated for BTEX and PHC fractions F1 and F2, and are presented in Tables 2.1 to 2.4. The equations below were used for all the above compounds. The BTEX guidelines were calculated using the chemical-specific parameters in Table 1.1.

The F1 and F2 guidelines were calculated separately for each of the sub-fractions, using chemical-specific parameters in Table 1.2. The guidelines for each sub-fraction were then combined using the same procedure as described in Section 3.6.1 for the protection of potable groundwater pathway. The only difference between the F1 and F2 guidelines calculated here, and those calculated in the Canada-Wide Standard is the substitution of the Alberta-specific recharge values (0.060 m/year and 0.012 m/year for Coarse and Fine soils, respectively, see Table 2.1 of Volume 1) for the Canada-Wide Standard value.

Values for SQG_{AL} and SQG_{GI} were not calculated for B(a)P, F3, or F4 because these compounds are only sparingly soluble in water, and thus would not be expected to have an appreciable concentration in discharging groundwater.

The SQG_{AL} and SQG_{GI} were calculated using the following equations. As noted in Volume 1, the calculation of these guidelines is based on the associated water quality guideline and a dilution factor calculated for each of four processes:

1. partitioning from soil to leachate;
2. transport of leachate from base of contamination to water table;
3. mixing of leachate and groundwater; and,
4. groundwater transport downgradient to surface water receptor.

The SQG_{AL} guideline for ethylbenzene in Coarse soil is provided as an example:

$$SQG_{AL} = C_{AL} DF$$

$$DF = DF1 \times DF2 \times DF3 \times DF4$$

where:

SQG_{AL}	=	soil quality guideline protective of groundwater for aquatic life, (mg/kg);
C_w	=	water quality guideline for aquatic life (0.090 mg/L; see Table 5.1);
DF	=	overall dilution factor (878 L/kg);
DF1	=	dilution factor 1, (2.81 L/kg);
DF2	=	dilution factor 2, (1.00);
DF3	=	dilution factor 3, (5.83); and,
DF4	=	dilution factor 4, (53.5).

Substituting these values in the above equations and rounding to 2 significant figures yields 79 mg/kg, which is the guideline for protection of freshwater aquatic life for ethylbenzene in Coarse soil (SQG_{AL}) (Tables 2.2 and 2.4). Note that the corresponding SQG_{GI} values for livestock and wildlife watering are calculated by multiplying the applicable water quality guideline (Table 5.1) by the same dilution factor. The calculations for the individual dilution factors are reproduced below.

4.3.1 Dilution Factor 1

Dilution factor 1 (DF1) is the ratio of the concentration of a contaminant in soil to the concentration in leachate that is in contact with the soil. This “dilution factor” represents the three phase partitioning between contaminant sorbed to soil, contaminant dissolved in pore water (i.e., as leachate), and contaminant present as soil vapour. DF1 is calculated using the following equation:

$$DF1 = K_{oc} f_{oc} \frac{(\theta_w + H' \theta_a)}{\rho_b}$$

where:

DF1	=	dilution factor 1 (L/kg);
K_{oc}	=	organic carbon partition coefficient (537 mL/g; see Table 1.1);
f_{oc}	=	fraction organic carbon (0.005 g/g; see Volume 1 Table 2.1);
θ_w	=	water filled porosity (0.119; see Volume 1 Table 2.1);
H'	=	dimensionless Henry’s Law constant (0.358; Table 1.1);
θ_a	=	air filled porosity (0.281; see Volume 1 Table 2.1); and,
ρ_b	=	dry soil bulk density (1.7 g/cm ³ ; see Volume 1 Table 2.1).

Substituting these values in the above equations yields a value for DF1 of 2.81 L/kg.

4.3.2 Dilution Factor 2

Dilution factor 2 (DF2) is the ratio of the concentration of a contaminant in leachate that is in contact with the soil, to the concentration in pore water just above the groundwater table. DF2 takes the value 1.00 (*i.e.*, no dilution) for generic guidelines because it is assumed at Tier 1 that the contaminated soil extends down to the water table.

4.3.3 Dilution Factor 3

Dilution factor 3 (DF3) is the ratio of the concentration of a chemical in pore water just above the groundwater table, to the concentration in groundwater beneath the source. This dilution factor reflects a decrease in concentration as leachate mixes with uncontaminated groundwater. DF3 is a function of groundwater velocity, infiltration rate, source length, and mixing zone thickness. The mixing zone thickness is calculated as being due to two processes: i) mixing due to dispersion, and ii) mixing due to infiltration rate. The equations used are as follows:

$$DF3 = 1 + \frac{Z_d V}{IX}$$

$$Z_d = r + s$$

$$r = 0.01X$$

$$s = d_a \left\{ 1 - \exp \left(\frac{-2.178XI}{Vd_a} \right) \right\}$$

$$V = Ki$$

where:

DF3	=	dilution factor 3 (dimensionless);
Z_d	=	average thickness of mixing zone (0.181 m; calculated above);
V	=	Darcy velocity in groundwater (16 m/year);
I	=	infiltration rate (0.060 m/year; see Volume 1 Table 2.1);
X	=	length of contaminated soil (10 m; see Volume 1 Table 4.1);
r	=	mixing depth due to dispersion (0.10 m; calculated above);
s	=	mixing depth due to infiltration rate (0.081 m; calculated above);
d_a	=	unconfined aquifer thickness (5 m; see Volume 1 Table 4.1);
K	=	aquifer hydraulic conductivity (320 m/year; see Volume 1 Table 2.1);
		and,

i = lateral hydraulic gradient in aquifer (0.05; see Volume 1 Table 3.2).

Substituting these values in the above equations yields a value for DF3 of 5.83.

4.3.4 Dilution Factor 4

Dilution factor 4 (DF4) accounts for the processes of dispersion and biodegradation as groundwater travels downgradient from beneath the source of contamination, and is the ratio of the concentration of a chemical in groundwater beneath the source, to the concentration in groundwater at a distance (10 m for Tier 1) downgradient of the source. DF4 was calculated using the following equations:

$$DF4 = \frac{4}{\exp(A) \times \operatorname{erfc}(B) \times [\operatorname{erf}(C) - \operatorname{erf}(D)]}$$

$$A = \frac{x}{2D_x} \left\{ 1 - \left(1 + \frac{4L_s D_x}{v} \right)^{1/2} \right\}$$

$$B = \frac{x - vt \left(1 + \frac{4L_s D_x}{v} \right)^{1/2}}{2(D_x vt)^{1/2}}$$

$$C = \frac{y + Y/2}{2(D_y x)^{1/2}}$$

$$D = \frac{y - Y/2}{2(D_y x)^{1/2}}$$

$$L_s = \frac{0.69I}{t_{1/2s}} \times \exp(-0.07d)$$

$$v = \frac{V}{\theta_t R_s}$$

$$R_s = 1 + \frac{\rho_b K_{oc} f_{oc}}{\theta_t}$$

$$D_x = 0.1x$$

$$D_y = 0.01x$$

where:

DF4	=	dilution factor 4 (dimensionless);
erf	=	the error function;
erfc	=	the complementary error function;
A	=	dimensionless group A (-3.89; calculated above);
B	=	dimensionless group B (-15.8; calculated above);
C	=	dimensionless group C (7.50; calculated above);
D	=	dimensionless group D (-7.50; calculated above);
x	=	distance to source (10 m; see Volume 1 Table 4.1);
D_x	=	dispersivity in the direction of groundwater flow (1.0 m; calculated);
L_s	=	decay constant (1.79 year ⁻¹ ; calculated above);
v	=	velocity of the contaminant (3.22 m/year; calculated above);
t	=	time since contaminant release (100 years; see Volume 1 Table 4.1);
y	=	distance to receptor perpendicular to groundwater flow (0 m; see Volume 1 Table 4.1);
Y	=	source width (30 m; see Volume 1 Table 4.1);
D_y	=	dispersivity perpendicular to the direction of groundwater flow (0.10 m; calculated above);
$t_{1/2s}$	=	decay half-life of chemical in aquifer (0.312 years; see Table 1.1);
d	=	water table depth (3 m; see Volume 1 Table 4.1);
V	=	Darcy velocity in groundwater (16 m/year; calculated);
θ_t	=	total soil porosity (0.40; see Volume 1 Table 2.1);
R_s	=	retardation factor in saturated zone (12.4; calculated above);
ρ_b	=	dry soil bulk density (1.7 g/cm ³ ; see Volume 1 Table 2.1);
K_{oc}	=	organic carbon partition coefficient (537 mL/g; see Table 1.1); and,
f_{oc}	=	fraction organic carbon (0.005 g/g; see Volume 1 Table 2.1).

Substituting these values in the above equations yields a value for DF4 of 53.5.

5 WATER QUALITY GUIDELINES

Two types of water quality guidelines are defined in this project.

Exposure Point water quality guidelines are applied to the water to which a receptor is actually exposed, and are used in this project as targets for calculating soil guidelines protective of various groundwater uses. Exposure Point water quality guidelines are summarized in Table 5.1, and are discussed in more detail in Section 5.1 below.

Groundwater quality guidelines provide a reference value to allow a determination of the quality of groundwater, and, for some water uses, take into account the effect of certain transport processes that

may occur between the point of groundwater measurement and the receptor. Groundwater quality guidelines are summarized in Table 5.2, and are discussed in more detail in Section 5.2 below.

5.1 Exposure Point Water Quality Guidelines

Exposure point water quality guidelines were compiled or calculated for BTEX and for PHC fractions F1 and F2 to protect the following water uses:

- human drinking water;
- freshwater aquatic life;
- livestock watering; and,
- wildlife watering.

Exposure point water quality guidelines are summarized in Table 5.1. Guidelines for F3, F4, and BaP are not required, since the low aqueous solubility and high K_{ow} of these hydrocarbons makes it unlikely that exposure to dissolved concentrations of these chemicals in water will be significant.

Where available and appropriate, CCME (1999) water quality guidelines are used. Otherwise, guidelines were calculated for this project. Example calculations are provided below.

5.1.1 Human Drinking Water

Human drinking water quality guidelines are summarized in Table 5.1. BTEX guidelines are available from Health Canada (1996b). Guidelines for F1 and F2 were calculated using the formula below. The guideline for PHC fraction F1 is calculated as an example.

$$\text{Drinking Water Guideline (mg/L)} = \left(\frac{BW \times TDI}{IR_w \times BIO_o} \right)$$

Where:

- BW = receptor body weight (16.5 kg (child, 0.5-4 years); see Volume 1 Table 2.4);
- TDI = tolerable daily intake for F1 (0.168 mg/kg-bw/day; see below);
- IR_w = drinking water ingestion rate (0.6 L/day (child, 0.5-4 years); see Volume 1 Table 2.4); and,
- BIO_o = oral bioavailability (gut absorption factor) (1.0; see Table 1.3).

Substituting these values in the above equations and rounding to 2 significant figures yields a drinking water guideline for PHC fraction F1 of 4.6 mg/L (Table 5.1). The calculation for TDI is reproduced below.

The tolerable daily intake for each fraction (F1 and F2) was calculated from the tolerable daily intake (TDI) for each sub-fraction as published by TPHCWG (1997), and the relative abundance of each sub-fraction in the fraction (Table 1.2), using the following formula:

$$\text{Tolerable Daily Intake for PHC Fraction (mg / kg - bw / day)} = \frac{1}{\sum_i \frac{F_i}{TDI_i}}$$

where:

- F_i = the assumed proportion of the fraction made up of sub-fraction i (dimensionless; see Table 1.2); and,
 TDI_i = the tolerable daily intake of sub-fraction i (mg/kg-bw/day; see Table 1.2).

$$\text{Tolerable Daily Intake for F1} = \frac{1}{\left(\frac{0.55}{5}\right) + \left(\frac{0.36}{0.1}\right) + \left(\frac{0.09}{0.04}\right)} = 0.168 \text{ mg / kg - bw / day}$$

5.1.2 Freshwater Aquatic Life

Exposure point water quality guidelines (AENV, 1999) for freshwater aquatic life are summarized in Table 5.1. Guidelines are available for benzene, toluene, and ethylbenzenes, but not xylenes. A guideline for xylenes was derived using the protocol published in CCME (1999). Details are included in Appendix I. Guidelines for F1 and F2 were calculated using the formula below. The freshwater aquatic life guideline for F1 is provided as an example.

$$\text{Exposure Point Aquatic Life Guideline for PHC Fraction (mg / L)} = \frac{1}{\sum_i \frac{F_i}{WQG_i}}$$

where:

- F_i = the assumed proportion of the fraction made up of sub-fraction i (dimensionless; see Table 1.2); and,
 WQG_i = the water quality guideline for sub-fraction i (mg/L; see Table 1.2).

$$\text{Exposure Point Aquatic Life Guideline for F1} = \frac{1}{\left(\frac{0.55}{0.0465}\right) + \left(\frac{0.36}{0.0076}\right) + \left(\frac{0.09}{0.14}\right)} = 0.017 \text{ mg / L}$$

5.1.3 Livestock and Wildlife Watering

Exposure point water quality guidelines for livestock/wildlife watering are summarized in Table 5.1. Livestock watering guidelines are available (CCME, 1999) for toluene, and ethylbenzene. However, these guidelines are based on the human smell and taste threshold for these chemicals. This project developed health-based livestock/wildlife watering guidelines for BTEX and F1 and F2. Watering guidelines for livestock and wildlife are calculated using parameters for dairy cows and mule deer, respectively (parameters available in Volume 1, Table 2.5). The wildlife watering guideline for F1 was calculated as an example:

$$\text{Livestock / Wildlife Watering Guideline (mg / L)} = \left(\frac{BW \times DTED}{IR_w \times BIO_o} \right)$$

Where:

- BW = body weight for mule deer (68 kg; see Volume 1 Table 2.5);
- DTED = daily threshold effect dose for F1 (9.74 mg/kg-bw/day; Table 1.3);
- IR_w = drinking water ingestion rate for mule deer (4.4 L/day; see Volume 1 Table 2.5); and,
- BIO_o = oral bioavailability (gut absorption factor) (1.0; see Table 1.3).

Substituting these values in the above equation and rounding to 2 significant figures yields a wildlife watering guideline for PHC fraction F1 of 150 mg/L (Table 5.1).

5.2 Groundwater Quality Guidelines

Groundwater water quality guidelines are summarized in Table 5.2, and were derived from exposure point water quality guidelines to protect the four water uses noted above. The procedure for each water use is discussed below.

5.2.1 Human Drinking Water

The groundwater quality guidelines for human drinking water are adopted directly from the corresponding exposure point water quality guidelines, based on the assumption that a drinking water well could potentially be drilled anywhere within a former upstream oil and gas facility. However, the groundwater quality guidelines for human drinking water need only be applied to groundwater that is in or potentially in hydraulic contact with a Domestic Use Aquifer, as defined by AENV (2001). Guidance on determining whether contaminated groundwater is in hydraulic contact with a Domestic Use Aquifer is provided in Section 3.6.4.

5.2.2 Livestock Watering

The groundwater quality guidelines for livestock watering are adopted directly from the corresponding exposure point water quality guidelines, based on the assumption that a dugout or water well for livestock watering could potentially be installed anywhere within a former upstream oil and gas facility. The groundwater quality guideline for livestock watering need only be applied where the land use is agricultural.

5.2.3 Freshwater Aquatic Life and Wildlife Watering

Two cases are considered for these two water uses. Separate guidelines are derived for groundwater less than 10 m from the nearest surface water body, and for groundwater more than 10 m from the nearest surface water body.

Groundwater Less Than 10 m From The Nearest Surface Water Body

For groundwater less than 10 m from the nearest surface water body, the exposure point water quality guidelines are adopted directly as groundwater quality guidelines. Note that no groundwater guidelines are provided in this category for F1 and F2, as the available data are not considered appropriate.

Groundwater More Than 10 m From The Nearest Surface Water Body

For groundwater more than 10 m from the nearest surface water body, the guidelines (“the >10 m guidelines”) are less stringent than the corresponding exposure point water quality guidelines. These less stringent guidelines are based on the assumption that groundwater transport processes will result in a decrease in concentration between the point of measurement and a receptor living in or drinking from a surface water body.

The >10 m guidelines are calculated by dividing the corresponding exposure point water quality guideline by the dilution factor from the saturated transport part of the calculation of the soil quality guideline for protection of ecological receptors (i.e., DF4 in Section 4.3.4). All the same parameters are used as in the calculation in Section 4.3.4, including the assumed 10 m offset. A set of guidelines for Coarse soil was calculated using the generic soil parameters for Coarse soil (Table 5.2). However, no valid guidelines could be calculated for Fine soil, because the model does not predict that hydrocarbon contamination in groundwater will travel as much as 10 m in this material. Accordingly no guidelines are required for groundwater more than 10 m from a surface water body in Fine soil for freshwater aquatic life or wildlife watering.

The groundwater quality guideline for protection of freshwater aquatic life is applicable to all land uses. The groundwater quality guideline for protection of wildlife watering is only applicable to natural area or agricultural land use.

6 REFERENCES

- AENV (Alberta Environmental Protection), 1999. Surface Water Quality Guidelines for Use in Alberta. Environmental Sciences Division. November 1999.
- AENV(Alberta Environment), 2001. Alberta Groundwater Quality Objectives (*in preparation*).
- ATSDR (Agency for Toxic Substances and Disease Registry), 1999. Toxicological Profile for Ethylbenzene. U.S. Department of Health and Human Services. U.S. Public Health Services.
- BCMELP (British Columbia Ministry of Environment, Lands and Parks), 1996. Overview of CSST Procedures for the Derivation of Soil Quality Matrix Standards for Contaminated Sites. BC Ministry of Environment, Lands and Parks.
- CCME (Canadian Council of Ministers of the Environment), 1996. A Protocol for the Derivation of Environmental and human Health Soil Quality Guidelines. Canadian Council of Ministers of the Environment. The National Contaminated Sites Remediation Program. March, 1996. CCME-EPC-101E.
- CCME (Canadian Council of Ministers of the Environment), 1999. Canadian Environmental Quality Guidelines. Canadian Council of Ministers of the Environment. Winnipeg.
- CCME (Canadian Council of Ministers of the Environment), 2000. Canada-Wide Standards for Petroleum Hydrocarbons (PHC) in Soil: Scientific Rationale, Supporting Technical Document. December, 2000.
- Environment Canada, 1998a. Development of Plant Toxicity Tests for Assessment of Contaminated Soils. Prepared for Method Development and Application Division, Technology Development Directorate, Environment Canada, Ottawa, Ontario, pp. 75 (Appendices).
- Environment Canada, 1998b. Development of Earthworm Toxicity Tests for Assessment of Contaminated Soils. Prepared for Method Development and Application Division, Technology Development Directorate, Environment Canada, Ottawa, Ontario, pp. 52 (Appendices).
- Environment Canada, 1998c. Development of a Reproduction Toxicity Test with *Onychiurus folsomi* for Assessment of Contaminated Soils. Prepared for Method Development and Application Division, Technology Development Directorate, Environment Canada, Ottawa, Ontario, pp. 250 (Appendices).
- ESG International Inc., 2001. Toxicity Assessment of BTEX Compounds. Report prepared for Dr. Ted Nason, Alberta Environment, Environmental Science Division. June 2001.
- Health Canada, 1992. Toluene: Priority Substances List Assessment Report No. 4. Health and Welfare Canada. Environment Canada. Ottawa, ON. En40-215/4E.
- Health Canada, 1993. Xylenes: Priority Substances List Assessment Report. Health Canada. Environment Canada. Ottawa, ON. En40-215/22E.
- Health Canada, 1996a. Health-Based Tolerable Daily Intakes/Concentrations and Tumorigenic Doses/Concentrations for Priority Substances. Health Canada, Environmental Health Directorate, Health Protection Branch. 96-EHD-194.

- Health Canada, 1996b. Guidelines for Canadian Drinking Water Quality, Sixth Edition. Federal-Provincial Subcommittee on Drinking Water of the Federal-Provincial Committee on Environmental and Occupational Health. Ref. 96-EHD-196.
- TPHCWG (Total Petroleum Hydrocarbon Criteria Working Group), 1997. Total Petroleum Hydrocarbon Criteria Working Group Series (4 Volumes).
- US EPA (United States Environmental Protection Agency), 2001. IRIS online database. <http://www.epa.gov/iris/>

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APPENDIX I

ECOLOGICAL TOXICITY DATA

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A1. INTRODUCTION

This Appendix provides background information on the toxicity data that were used to derive benzene, toluene, ethylbenzene, and xylenes (BTEX) exposure limits for ecological receptors. Exposure limits for the four petroleum hydrocarbon (PHC) fractions F1 to F4 were adopted directly from CCME (2000), and are summarized in Tables 1.2 and 1.3 of the main text. BTEX exposure limits for three groups of receptors are discussed:

- Plants, soil invertebrates, and micro-organisms (Section 2);
- livestock and wildlife (Section 3); and,
- freshwater aquatic life (Section 4).

A2. PLANTS, SOIL INVERTEBRATES AND MICRO-ORGANISMS

Data on the toxicity of the chemicals of concern to terrestrial plants, invertebrates and microorganisms are required to assess the ecological soil contact pathway, and to calculate the soil quality guideline for soil contact (SQG_{SC}). Existing data are reviewed in Section 2.1 below. These data are not used in the guideline derivation process, due to uncertainties in the protocols used for determining the toxicity of volatile compounds in soil. A new study was commissioned for this report. This work is described in Section 2.2, and is used as the basis for guideline derivation of the ecological soil contact pathway.

A2.1 Review of Existing Data

In this Section, the existing data on the toxicity of the chemicals of concern to terrestrial plants, invertebrates and microorganisms are reviewed. Significant advances in the techniques for determining the toxicity of highly volatile compounds in soil have been made in the last few years, and a new set of protocols is available (Environment Canada, 1998a,b,c). It is not clear whether the protocols used to obtain the existing data were acceptable based on the standards noted above. Accordingly, none of these data are used in the guideline derivation process, and they are included for completeness only.

A2.1.1 Benzene

Existing benzene data are reviewed below.

Invertebrates

Environment Canada (1995) conducted a series of experiments on earthworms (*Eisenia foetida*). The 7-day LC₂₅ values were reported to be 42 and 280 mg/kg for the two soils tested. The NOEC and LOEC for growth (*Eisenia foetida*) were 4% and 8% (dry weight), respectively, for a 4 mm layer of sludge applied to the surface of a silt loam (Hartenstein, 1982). The NOEC for survival was 8%

(Hartenstein, 1982). In two filter paper contact tests, the LC_{50} for the earthworm *Eisenia foetida* were $98 \mu\text{g}/\text{cm}^2$ (Neuhauser *et al.*, 1985) and $6.15 \mu\text{g}/\text{kg}$ (Callahan *et al.*, 1994). An air concentration of $10,000 - 210,000 \text{ mg}/\text{m}^3$ is reportedly lethal to insects (Miller *et al.*, 1976).

Plants

Environment Canada (1995) conducted a series of experiments on radish (*Raphanus sativa*) and lettuce (*Lactuca sativa*). The reported EC_{25} values for seedling emergence were 22 and 26 mg/kg for radishes and 7.0 and 73 mg/kg for lettuce. The reported EC_{25} values for root elongation were 14 and 127 mg/kg for radishes and 30 and 56 mg/kg for lettuce. Lettuce (*Lactuca sativa*) germination EC_{50} in agar was greater than 78 mg/L (solubility limit for benzene) (Reynolds, 1989).

An air concentration of $10,000 \text{ mg}/\text{m}^3$ is acutely toxic to plants (Miller *et al.*, 1976). The LC_{50} (benzene vapours) for runner bean (*Phaseolus multiflorus*) and parsnip leaves was reported to be 154×10^5 and $269 \times 10^5 \text{ mol}/\text{L}$, respectively (Ivens, 1952). The EC_{50} (benzene vapours) for tobacco (*Nicotiana tabacum*) pollen germination was 36.5 mg/L (Schubert *et al.*, 1995).

An 8-hour exposure to benzene vapours at 1.2 mM/L resulted in trace injury (as measured by leaf damage) to barley plants. A ½-hour and 1-hour exposure to vapours at 2.7 mM/L resulted in 95% and 100% injury, respectively to barley plants. A 2-hour exposure at 2.7 and 3.0 mM/L resulted in 0% and 10% injury, respectively to carrot plants (Currier and Peoples, 1954). A 2-hour exposure to benzene vapours at $3.2 \times 10^{-4} \text{ M}$ resulted in 100% injury (as measured by leaf damage) in barley and tomato plants and 95% injury in carrot plants. A ¼-hour exposure resulted in 60% injury in barley, 80% injury in tomato plants and 0% injury in carrot plants. Benzene vapours at $2.2 \times 10^{-4} \text{ M}$ resulted in 2% injury in barley following a ¼-hour exposure and 25% injury following a 4-hour exposure. Vapours at $6.4 \times 10^{-4} \text{ M}$ resulted in 40% injury in barley following a ¼-hour exposure and 100% injury following a ½-hour exposure (Currier, 1951).

Soil Microorganisms

Microbial respiration was not affected at benzene levels of 1,000 mg/kg in a silt loam but a transient decrease in microbial respiration did occur in a sandy loam at 1,000 mg/kg (Walton *et al.*, 1989). No effects on soil microorganisms occurred at a soil concentration of 100 mg/kg (Anderson *et al.*, 1991). Ammonia oxidation EC_{50} by the soil bacterium *Nitrosomonas europaea* was reported to be 132 μM (soil solution) (Keener and Arp, 1994).

A2.1.2 Toluene

Existing toluene data are reviewed below.

Invertebrates

Environment Canada (1995) conducted a series of experiments on earthworms (*Eisenia foetida*). The 7-day LC_{25} values were reported to be 77 and 11 mg/kg for the two soils tested. The earthworm

(*Eisenia foetida*) NOEC for appearance was reported to be between 15 and 50 mg/kg, while the LC₅₀ was between 150 and 280 mg/kg (Sloof and Blokzijl, 1988). Both the LC₅₀ and NOEC for earthworm (*Eisenia foetida*) survival were between 222 and 400 mg/kg. The NOEC for reproduction was between 71 and 222 mg/kg (Vonk *et al.*, 1986). The NOEC and LOEC for growth (*Eisenia foetida*) were 0.1% and 1.0% (dry weight), respectively for a 4 mm layer of sludge applied to the surface of a silt loam. The NOEC and LOEC for survival were 1.0 and 4%, respectively (Hartenstein, 1982).

In two filter paper contact test with the earthworm *Eisenia foetida*, the LC₅₀ was reported to be 75 µg/cm² (Neuhausser *et al.*, 1985) and 4.18 µg/kg (Callahan *et al.*, 1994). Nematode abundance and arthropod activity were not affected at 20 µg/mL (soil solution) (Fuller *et al.*, 1997).

Plants

Environment Canada (1995) conducted a series of experiments on radish (*Raphanus sativa*) and lettuce (*Lactuca sativa*). The reported EC₂₅ values for seedling emergence were 7.1 mg/kg for radishes and 8.6 and 9.8 mg/kg for lettuce (Note: the second EC₂₅ values for radishes could not be calculated). The reported EC₂₅ values for root elongation were 14 and 7.0 mg/kg for radishes and 3.7 and 5.9 mg/kg for lettuce. Plant growth inhibition and chlorosis occurred at a soil concentration of 1,000 mg/kg (wet weight) (Sloof and Blokzijl, 1988). Lettuce (*Lactuca sativa*) shoot growth EC₅₀ was >1,000 mg/kg (Hulzebos *et al.*, 1993).

Corn and soybean germination NOEC = 20,000 mg/kg in clay. Soybean shoot weight NOEC and LOEC (32% reduction) = 2,000 and 20,000 mg/kg, respectively in clay. Corn shoot weight LOEC (30% reduction) = 200 mg/kg. Soybean germination NOEC and LOEC (50% reduction) = 200 and 2,000 mg/kg, respectively in a sandy loam at pH 4. Corn germination NOEC and LOEC (86% reduction) = 2,000 and 20,000 mg/kg, respectively in a sandy loam at pH 4. Soybean, corn and fescue germination was not affected at 20,000 mg/kg in a sandy loam at pH 6. Soybean shoot weight LOEC (40% reduction) = 200 mg/kg in a sandy loam at pH 6. Corn shoot weight NOEC and LOEC (68% reduction) = 2,000 and 20,000 mg/kg, respectively in a sandy loam at pH 6. Fescue shoot weight NOEC and LOEC (22% reduction) = 2,000 and 20,000 mg/kg, respectively in a sandy loam at pH 6 (Overcash *et al.*, 1982).

Seed germination was not affected at 20 µg/mL (soil solution) (Fuller *et al.*, 1997). Plant growth inhibition and chlorosis occurred at a water concentration of 500 mg/L (Sloof and Blokzijl, 1988). Lettuce (*Lactuca sativa*) shoot growth EC₅₀ was 16 mg/L (solution) (Hulzebos *et al.*, 1993).

The LC₅₀ for runner bean (*Phaseolus multiflorus*) and parsnip leaves was 47.5 x 10⁵ and 96.7 x 10⁵ mol/L, respectively (Ivens, 1952). The EC₂₅ and EC₅₀ (vapours) for tobacco (*Nicotiana tabacum*) pollen germination were 9.8 and 28.9 mg/L (Schubert *et al.*, 1995). A 2-hour exposure to toluene vapours at 1.3 x 10⁻⁴ M resulted in 100% injury (as measured by leaf damage) in barley and tomato plants and 98% injury in carrot plants. A ¼-hour exposure resulted in 70% injury in barley, 85% injury

in tomato plants and 0% injury in carrot plants. Toluene vapours at 0.69×10^{-4} M resulted in 2% injury in barley following a ¼-hour exposure and 50% injury following a 2-hour exposure. Vapours at 4.9×10^{-4} M resulted in 100% injury in barley following a ¼-hour exposure (Currier, 1951).

Soil Microorganisms

The NOEC for microbial respiration and ammonification ranged from 100 – 1,300 mg/kg while the NOEC for nitrification was <26 mg/kg (Sloof and Blokzijl, 1988). Vonk *et al.* (1986) reported the NOEC for microbial respiration to be between 300 – 1,000 mg/kg and the NOEC for nitrification to be <20 mg/kg. A transient increase in microbial respiration occurred at 1,000 mg/kg in a silt loam while a transient decrease occurred in a sandy loam (Walton *et al.*, 1989). A concentration of 25 mg/kg had no effect on microbial respiration (Kirchmann *et al.*, 1991) and no effects on soil microorganisms were reported at a soil concentration of 100 mg/kg (Anderson *et al.*, 1991).

There was no effect on ammonification or soil denitrification at 20 µg/mL (soil solution) (Fuller and Scow, 1997). The NOEC and LOEC for toxicity to toluene degrading microorganisms was 625 and 1,000 µg/mL (soil solution), respectively (Mu and Scow, 1994). The ammonia oxidation EC_{50} by the soil bacterium *Nitrosomonas europaea* was 106 µM (soil solution) (Keener and Arp, 1994). Microbial diversity NOEC and LOEC were reported to be 60 and 100 µg/mL (soil solution), respectively (Fuller *et al.*, 1997). Total culturable heterotrophs were slightly reduced at 200 µg/mL (soil solution) (Fuller *et al.*, 1997). Ammonia oxidation NOEC and LOEC were 20 and 60 µg/mL (soil solution), respectively while the nitrite oxidation NOEC and LOEC were 60 and 100 µg/mL (soil solution), respectively (Fuller and Scow, 1996).

A2.1.3 Ethylbenzene

Existing ethylbenzene data are reviewed below.

Invertebrates

Environment Canada (1995) conducted a series of experiments on earthworms (*Eisenia foetida*). The 7-day LC_{25} values were reported to be 59 and 166 mg/kg for the two soils tested. In two filter paper contact test, the earthworm (*Eisenia foetida*) LC_{50} was 47 µg/cm² (Neuhauser *et al.*, 1985) and 4.93 µg/kg (Callahan *et al.*, 1994).

Plants

Environment Canada (1995) conducted a series of experiments on radish (*Raphanus sativa*) and lettuce (*Lactuca sativa*). The reported EC_{25} values for seedling emergence were 16 and 7.0 mg/kg for radishes and 7.0 and 5.0 mg/kg for lettuce. The reported EC_{25} values for root elongation were 31 and 70 mg/kg for radishes and 5.8 and 24 mg/kg for lettuce. The LC_{50} (ethylbenzene vapours) for runner bean (*Phaseolus multiflorus*) and parsnip leaves was 25.5×10^5 and 45.2×10^5 mol/L, respectively (Ivens, 1952).

Soil Microorganisms

The ammonia oxidation EC_{50} by the soil bacterium *Nitrosomonas europaea* was 143 μ M (soil solution) (Keener and Arp, 1994).

A2.1.4 Xylenes

Existing xylenes data are reviewed below.

Invertebrates

Environment Canada (1995) conducted a series of experiments on earthworms (*Eisenia foetida*). The 7-day LC_{25} values were reported to be 48 and 63 mg/kg for the two soils tested. The LC_{50} for the grain weevil (*Calandra granaria*) was 31 g/m³ for *o*-xylene and 48 g/m³ for *p*-xylene (Miller *et al.*, 1976). A dose of 0.002 mL was toxic to the housefly (*Musca domestica*) (Miller *et al.*, 1976).

Plants

Environment Canada (1995) conducted a series of experiments on radish (*Raphanus sativa*) and lettuce (*Lactuca sativa*). The reported EC_{25} values for seedling emergence were 14 and 49 mg/kg for radishes and 1.5 and 8.1 mg/kg for lettuce. The reported EC_{25} values for root elongation were 1.2 and 0.10 mg/kg for radishes and 0.5 and 0.18 mg/kg for lettuce. Lettuce (*Lactuca sativa*) shoot growth EC_{50} was reported to be >1,000 mg/kg for *o*-xylene (Hulzebos *et al.*, 1993).

Sugar beet root growth was reduced by 31.5%, 29.1% and 23.6% when exposed to a 100, 200 and 500 mg/L solution, respectively (Allen *et al.*, 1961). Lettuce (*Lactuca sativa*) shoot growth EC_{50} was reported to be between 1 and 3.2 mg/L (solution) for *o*-xylene (Hulzebos *et al.*, 1993). Germination of beans, oats, lettuce, and radishes were affected by 0.1 mg/L in water (Miller *et al.*, 1976). There were no detectable signs of injury or loss of crop yield (alfalfa, squash, potatoes, tomatoes, dwarf corn and beans) when xylenes was applied at 370, 740 or 1480 mg/L (Bruns and Kelly, 1974).

The LC_{50} (xylenes vapours) for runner bean (*Phaseolus multiflorus*) and parsnip leaves was 22.9×10^5 and 37.7×10^5 mol/L, respectively for *p*-xylene and 18.4×10^5 and 27.6×10^5 mol/L, respectively for *o*-xylene (Ivens, 1952). The EC_{50} (vapours) for tobacco (*Nicotiana tabacum*) pollen germination was 17.1 mg/L (Schubert *et al.*, 1995). A 2-hour exposure to xylene vapours at 0.46×10^{-4} M resulted in 98% injury (as measured by leaf damage) in barley, 95% injury in tomato plants and 25% injury in carrot plants. A ¼-hour exposure resulted in 75% injury in barley, 40% injury in tomato plants and 0% injury in carrot plants. Xylene vapours at 0.20×10^{-4} M resulted in 2% injury in barley following a 2-hour exposure and 80% injury following a 4-hour exposure. Vapours at 2.4×10^{-4} M resulted in 95% injury in barley following a ¼-hour exposure and 100% injury following a 1-hour exposure (Currier, 1951).

Soil Microorganisms

Microbial respiration was not affected at 1,000 mg/kg in a silt loam but a transient decrease did occur in a sandy loam (Walton *et al.*, 1989). No effects on soil microorganisms were reported at a soil concentration of 100 mg/kg *p*-xylene (Anderson *et al.*, 1991). Ammonia oxidation was reduced by >90% at 100 µg/mL (soil solution) (Hansson *et al.*, 1991) and the ammonia oxidation EC₅₀ by the soil bacterium *Nitrosomonas europaea* was 74 µM (soil solution) (Keener and Arp, 1994).

A2.2 New Data

A new study was commissioned to determine the toxicity of BTEX compounds to one plant species and one terrestrial earthworm species, using up to date protocols for toxicity tests with volatile compounds (ESG, 2001). A single plant species was considered acceptable for this work, because the species chosen was the most sensitive species in work done for the petroleum hydrocarbon Canada-Wide Standard (CCME, 2000). The study was undertaken by ESG International, with the following scope:

- test species were *Eisenia andrei* (earthworm) and *Agropyron dasystachyum* (early northern wheatgrass);
- earthworm tests measured 7 and 14 day mortality endpoints;
- wheatgrass tests measured seedling emergence, shoot and root length and dry and wet biomass endpoints, all at 14 days;
- Two soils were used: “Artificial Soil” was a Coarse soil; and “Alberta Till” was a Fine soil;
- procedures were adopted to minimize loss of volatile compounds from the tests; and,
- chemical analysis was undertaken at the start of the tests to estimate the actual concentrations of BTEX compounds to which the organisms were exposed at the start of the tests.

The results of the ESG (2001) study for Fine and Coarse soils are summarized in Tables A-1 and A-2, respectively. As noted in Section 2.1, none of the existing BTEX toxicity data were used for guideline derivation, due to uncertainties in the protocols that were used. Accordingly, the data in Tables A-1 and A-2 were used as the basis for guideline derivation.

The derivation of the soil quality guideline for soil contact (SQG_{SC}) followed the procedure developed for other hydrocarbon compounds in the PHC CWS (CCME, 2000). This procedure was as follows:

- for each distinct test/endpoint, only the data representing a 50% effect are considered (*i.e.*, median lethal concentration (LC₅₀) or 50% inhibition concentration (IC₅₀));
- if tests differ only in duration, only data for the longest duration are used;
- if multiple data are available for the same chemical, endpoint and species, these data are replaced by their geometric mean;
- for natural area, agricultural, or residential land use, the SQG_{SC} was calculated as the 25th percentile of plant and invertebrate data; and,
- for commercial and industrial land use, the SQG_{SC} was calculated as the 50th percentile of plant data only.

The 25th percentile of plant and invertebrate data and the 50th percentile of plant data are included in Tables A-1 and A-2. These numbers are adopted as the SQG_{SC} guideline values for surface soil (see Tables 2.1 and 2.2 in this report).

SQG_{SC} values for subsoil are calculated based on the PHC CWS (CCME, 2000). In the PHC CWS, subsoil guidelines were between 2 and 6 times greater than the surface soil guidelines, based on the lower biological activity levels at subsoil depths, but also taking into account other considerations such as aesthetics, safety, and underground infrastructure. In this document, subsoil guidelines for this pathway are calculated as twice the corresponding surface soil guideline, except in cases where this would result in a pore water concentration close to the solubility of the compound in question, in which case the corresponding surface soil guideline was adopted directly as the subsoil guideline. Subsoil guidelines are summarized in Tables 2.3 and 2.4 of this report.

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A3. LIVESTOCK/WILDLIFE

Two ecological pathways involving the protection of livestock/wildlife are considered in this project. The pathways are soil ingestion and protection of groundwater for ingestion. Daily threshold effects dose (DTED) values for BTEX were developed as toxicological limits for these pathways. DTED values for BTEX are summarized in Table 1.1 in the main text. DTED values for the four PHC fractions are adopted directly from CCME (2000) and are summarized in Table 1.3. A DTED is defined as a dose level below which adverse effects are not expected in a receptor.

DTEDs for livestock or wildlife have not generally been developed by regulatory agencies. However, development of the DTED follows a similar process as that for the development of a human limit and, thus, can be based on the same experimental study. Therefore, in the calculations below, the DTED is based on the same study that is used by the regulatory agencies for the human exposure limit.

A3.1 Benzene

The oral DTED for benzene applied in this project (0.08 mg/kg-bw/day), was derived based on the reported LOAEL (Lowest-Observed-Adverse-Effect-Level) from a study by Hsieh *et al.* (1988). Mice were exposed to benzene in drinking water at doses ranging from 0 to 180 mg/kg-bw/day for 28 days (water concentrations ranged from 0 to 790 mg/L). The reported LOAEL, based on hematological anemia and immunological effects, was 8 mg/kg-bw/day. A 100-fold uncertainty factor was applied, based on a 10-fold factor to account for the use of a LOAEL from a less than chronic duration study, and a further 10-fold factor to account for the uncertainties in extrapolating from one species to another.

$$DTED(\text{benzene}) = \frac{8}{100} = 0.08 \text{ mg/kg} - \text{bw/day}$$

A3.2 Toluene

The oral DTED for toluene applied in this project (4.46 mg/kg-bw/day), was derived based on the reported LOAEL from a study by the National Toxicology Program (1989). Rats were orally gavaged with doses ranging from 0 to 5,000 mg/kg in corn oil for 13 weeks (5 days/week). The reported LOAEL, based on organ weight and histopathologic changes in the liver and kidney, was 625 mg/kg-bw/day. When adjusted for a continuous exposure (*i.e.*, to 7 days/week from 5 days/week), the LOAEL becomes 446 mg/kg-bw/day. A 100-fold uncertainty factor was applied, based on a 10-fold factor to account for the use of a LOAEL from a less than chronic duration study, and a further 10-fold factor to account for the uncertainties in extrapolating from one species to another.

$$DTED(\text{toluene}) = \frac{625 \times (5/7)}{100} = 4.46 \text{ mg/kg} - \text{bw/day}$$

A3.3 Ethylbenzene

The oral DTED for ethylbenzene applied in this project (2.91 mg/kg-bw/day), was derived based on the reported LOAEL from a study by Wolf *et al.* (1956). Rats were orally gavaged with doses ranging from 14 to 680 mg/kg in olive oil for 182 days (5 days/week). The reported LOAEL, based on histopathologic changes in the liver and kidney, was 408 mg/kg-bw/day. When adjusted for a continuous exposure (i.e., to 7 days/week from 5 days/week), the LOAEL becomes 291 mg/kg-bw/day. A 100-fold uncertainty factor was applied, based on a 10-fold factor to account for the use of a LOAEL from a less than chronic duration study, and a further 10-fold factor to account for the uncertainties in extrapolating from one species to another.

$$DTED \text{ (ethylbenzene)} = \frac{408 \times (5/7)}{100} = 2.91 \text{ mg/kg} - \text{bw/day}$$

A3.4 Xylenes

The oral DTED for xylenes applied in this project (11.9 mg/kg-bw/day), was derived based on the reported LOAEL from a study by the National Toxicology Program (1986). Rats were orally gavaged with doses ranging from 0 to 1,000 mg/kg for 103 weeks (5 days/week). The reported LOAEL, based on central nervous system toxicity, was 500 mg/kg-bw/day. When adjusted for a continuous exposure (i.e., to 7 days/week from 5 days/week), the LOAEL becomes 357 mg/kg-bw/day. A 30-fold uncertainty factor was applied, based on a 3-fold uncertainty factor to account for uncertainties within the toxicological database, and a further 10-fold factor to account for the uncertainties in extrapolating from one species to another.

$$DTED \text{ (xylenes)} = \frac{500 \times (5/7)}{30} = 11.9 \text{ mg/kg} - \text{bw/day}$$

A4. FRESHWATER AQUATIC LIFE

Freshwater aquatic life water quality guidelines were required for this project, in order to derive soil quality guidelines protective of freshwater aquatic life. Water quality guidelines for freshwater aquatic life are available for benzene, toluene, and ethylbenzene (AENV, 1999; CCME, 1999). A freshwater aquatic life guideline has not been developed by these agencies for xylenes.

A significant amount of data are available concerning the freshwater aquatic toxicity of xylenes. These data, downloaded from the US EPA ECOTOX database (US EPA 2001), are summarized in Table A-3. Note that data for marine or estuarine species, and data for non-toxicological effects (e.g., avoidance) are not included. References are included in Table A-3, but are not reproduced in the

references in Section 5. A full review of the source papers of these data, including a check for compliance with the requirements of the CCME (1999) protocol for developing water quality guidelines for freshwater aquatic life, is outside the scope of this report.

The dataset was simplified and reduced as follows:

- multiple data points for the same species, endpoint, effect, and duration were combined by taking the geometric mean; and,
- where data points were available for the same species, endpoint, and effect, but different durations, only the longest duration data were considered.

The reduced data is presented in Table A-4.

A working value for a xylenes freshwater aquatic life guideline for the current project was developed based on the lowest concentration in the reduced dataset (3,643 µg/L, 48 hr *Daphnia magna* immobilization EC50, Table A-2). This value was used, together with an application factor of 0.05 (acute test for a non-persistent variable) to give a guideline value of 180 µg/L for use in the current work. This calculation was based on the CCME (1999) protocol. A non-persistent variable is defined by CCME (1999) as having a degradation half life less than 8 weeks. The degradation half life of xylenes in surface water is given by Howard *et al.*, 1991 as 1-4 weeks. It should be noted that the issue of getting meaningful aquatic toxicity data from volatile compounds would need further study before deriving a definitive xylenes guideline.

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A5. REFERENCES

- AENV (Alberta Environmental Protection), 1999. Surface Water Quality Guidelines for Use in Alberta. Environmental Sciences Division. November 1999.
- Allen, W.R., W. L. Askew and K. Schreiber, 1961. Effect of insecticide fertilizer mixtures and seed treatment on emergence of sugar beet seedlings. *J. Econ. Entomol.* **54**:181-187.
- Anderson, T.A., J.J. Beauchamp and B.T. Walton, 1991. Organic chemicals in the environment: fate of volatile and semivolatile organic chemicals in soils: abiotic versus biotic losses. *J. Environ. Qual.*, **20**, 420-424.
- Bruns, V.F. and A.D. Kelly, 1974. Effect of Sprinkler Irrigation with Xylene-Treated Water on Six Crops. Bulletin 796. College of Agriculture Research Centre. Washington State University. Cited in CCME, 1999.
- Callahan, C.A., M.A. Shirazi and E.F. Neuhauser, 1994. Co`mparative toxicity of chemicals to earthworms. *Environ. Toxicol. Chem.*, **13**, 291-298.
- CCME (Canadian Council of Ministers of the Environment), 1999. Canadian Environmental Quality Guidelines. Canadian Council of Ministers of the Environment. Winnipeg.
- CCME (Canadian Council of Ministers of the Environment), 2000. Canada-Wide Standards for Petroleum Hydrocarbons (PHC) in Soil: Scientific Rationale, Supporting Technical Document. December, 2000.
- Currier, H.B. and S.A. Peoples, 1954. Phytotoxicity of hydrocarbons. *Hilgardia*, **23**, 155-173.
- Currier, H.B., 1951. Herbicidal properties of benzene and certain methyl derivatives. *Hilgardia*, **20**, 383-406.
- Efroymsen, R.A., M.E. Will, G.W. Suter II and A.C. Wooten, 1997. Toxicological Benchmarks for Screening Contaminants for Potential Concern for Effects on Terrestrial Plants: 1997 Revisions. Prepared for the U.S. Department of Energy. Lockheed Martin Energy Systems, Inc. Oak Ridge National Laboratory. ES/ER/TM-85/R3.
- Environment Canada, 1995. Toxicity Testing of National Contaminated Sites Remediation Program Priority Substances for the Development of Soil Quality Guidelines for Contaminated Sites. Environmental Conservation Service, Evaluation and Interpretation Branch, Guidelines Division. Ottawa, ON. Unpublished.
- Environment Canada, 1998a. Development of Plant Toxicity Tests for Assessment of Contaminated Soils. Prepared for Method Development and Application Division, Technology Development Directorate, Environment Canada, Ottawa, Ontario, pp. 75 (Appendices).

A5. References

- Environment Canada, 1998b. Development of Earthworm Toxicity Tests for Assessment of Contaminated Soils. Prepared for Method Development and Application Division, Technology Development Directorate, Environment Canada, Ottawa, Ontario, pp. 52 (Appendices).
- Environment Canada, 1998c. Development of a Reproduction Toxicity Test with *Onychiurus folsomi* for Assessment of Contaminated Soils. Prepared for Method Development and Application Division, Technology Development Directorate, Environment Canada, Ottawa, Ontario, pp. 250 (Appendices).
- ESG International Inc., 2001. Toxicity Assessment of BTEX Compounds. Report prepared for Dr. Ted Nason, Alberta Environment, Environmental Science Division. June 2001.
- Fuller, M.E. and K.M. Scow, 1996. Effects of toluene on microbially-mediated processes involved in the soil nitrogen cycle. *Microbial Ecology*, **32**, 171-184.
- Fuller, M.E. and K.M. Scow, 1997. Impact of trichloroethylene and toluene on nitrogen cycling in soil. *Appl. Environ. Microbiol.*, **63**, 4015-4019.
- Fuller, M.E., K.M. Scow, S. Lau and H. Ferris, 1997. Trichloroethylene (TCE) and toluene effects on the structure and function of the soil community. *Soil Biol. Biochem.*, **29**, 75-89.
- Hansson, G.B., L. Klemetsson, J. Stenstrom and L. Torstensson, 1991. Testing the influence of chemicals on soil autotrophic ammonium oxidation. *Environ. Toxicol. Water Qual.*, **6**, 351-360. Cited in Fuller and Scow, 1996.
- Hartenstein, R., 1982. Effect of aromatic compounds, humic acids and lignins on growth of the earthworm *Eisenia foetida*. *Soil Biol. Biochem.*, **14**, 595-599.
- Howard, P.H., Boethling, R.S., Jarvis, W.F., Meylan, W.M., and Michalenko, E.M., 1991. Environmental Degradation Rates. Lewis Publishers Inc., Chelsea, MI, 725 p.
- Hsieh, G.C., R.P. Sharma and R.D.R. Parker, 1988. Subclinical effects of groundwater contaminants. I. alteration of humoral and cellular immunity by benzene in CD-1 mice. *Arch. Environ. Contam. Toxicol.*, **17**, 799-805. cited in U.S. EPA, 1998.
- Hulzebos, E.M., D.M.M. Adema, E.M. Dirven-van Breemen, L. Henzen, W.A. van Dis, H.A. Herbold, J.A. Hoekstra, R. Baerselman and C.A.M. van Gestel, 1993. Phytotoxicity Studies with *Lactuca sativa* in Soil and Nutrient Solution. *Environ. Toxicol. Chem.* **12**:1079-1094.
- Ivens, G.W., 1952. The phytotoxicity of mineral oils and hydrocarbons. *Ann. Appl. Biol.*, **39**, 418-422.
- Keener, W.K. and D.J. Arp, 1994. Transformations of aromatic compounds by *Nitrosomonas europaea*. *Appl. Environ. Microbiol.*, **60**, 1914-1920.
- Kirchmann, H., H. Astrom and G. Jonsall, 1991. Organic pollutants in sewage sludge: 1. effects of toluene, naphthalene, 2-methylnaphthalene, 4-n-nonylphenol and di-2-ethylhexyl phthalate on soil biological processes and their decomposition in soil. *Swedish J. Agric. Res.*, **21**, 107-113.
- Miller, T.A., R.H. Rosenblatt, J.C. Darce, J.G. Pearson, R.K. Kulkarni, J.L. Welch, D.R. Cogley and G. Woodard, 1976. Problem Definition on Potential Environmental Pollutants IV: Physical, Chemical, Toxicological and Biological Properties of Benzene, Toluene, Xylenes and p-

A5. References

- Chlorophenyl Methyl Sulfide, Sulfoxide and Sulfone. U.S. Army Medical Bioengineering Research and Development Laboratory. Fredrick, MD. AD/A-040 435. Cited in Environment Canada, 1984 and Environment Canada, 1993.
- Mu, D.Y. and K.M. Scow, 1994. Effect of trichloroethylene (TCE) and toluene concentrations on TCE and toluene biodegradation and the population density of TCE and toluene degraders in soil. *Appl. Environ. Microbiol.*, 60, 2661-2665.
- National Toxicology Program, 1986. NTP Technical Report of the Toxicology and Carcinogenesis of Xylenes (mixed) (60.2% m-xylene, 13.6% p-xylene, 17.0% ethylbenzene and 9.1% o-xylene) (CAS No. 1330-20-7) in F344/N Rats and B6C3F1 Mice (gavage studies). U.S. DHHS, PHS, NIH, NTP, Research Triangle Park, NC. NTP TR 327, NIH Publ. No. 86-2583. cited in U.S. EPA, 2000.
- National Toxicology Program, 1989. Toxicology and Carcinogenesis Studies of Toluene in F344/N Rats and B6C3F1 Mice. Technical Report Series No. 371. Research Triangle Park, NC. cited in U.S. EPA, 2000.
- Neuhauser, E.F., R.C. Loehr, M.R. Malecki, D.L. Milligan and P.R. Durkin, 1985. The toxicity of selected organic chemicals to the earthworm *Eisenia fetida*. *J. Environ. Qual.*, 14, 383-388.
- Overcash, R.M., J.B. Weber and M.L. Miles, 1982. Behavior of Organic Priority Pollutants in the Terrestrial System: Di-n-Butyl Phthalate Ester, Toluene, and 2,4 Dinitrophenol. UNC-WRRI-82-171. Water Resources Research Institute. University of North Carolina. Cited in Efroymsen *et al.*, 1997.
- Reynolds, T., 1989. Comparative effects of heterocyclic compounds on inhibition of lettuce fruit germination. *J. Exper. Bot.*, 40, 391-404.
- Schubert, U., L. Wisanowsky and U. Kull, 1995. Determination of phytotoxicity of several volatile organic compounds by investigating the germination pattern of tobacco pollen. *J. Plant Physiol.*, 145, 514-518.
- Sloof, W. and P.J. Blokzijl (eds.), 1988. Integrated Criteria Document Toluene. RIVM Research for Man and Environment. National Institute of Public Health and Environmental Protection. The Netherlands. Report No. 758473010. Cited in Environment Canada, 1992.
- US EPA (U.S. Environmental Protection Agency), 1998. Toxicological Review of Benzene (Noncancer Effects) (CAS No. 71-43-2). In Support of Summary Information on the Integrated Risk Information System (IRIS). Draft. U.S. Environmental Protection Agency. Washington, DC.
- US EPA (U.S. Environmental Protection Agency), 2000. Integrated Risk Information System (IRIS). on-line database. U.S. Environmental Protection Agency.
- US EPA (U.S. Environmental Protection Agency), 2001. IRIS online database. <http://www.epa.gov/iris/>
- Vonk, J.W., D.M.M. Adema and D. Barug, 1986. Comparison of the Effects of Several Chemicals on Microorganisms, Higher Plants and Earthworms. In: Assink, J.W. and W.J. van den Brink (eds.).

A5. References

- Contaminated Soil. First International TNO Conference on Contaminated Soil 11-15 November, 1985, Utrecht, The Netherlands. Martinus Nijhoff Publishers. Dordrecht, The Netherlands.
- Walton, B.T., T.A. Anderson, M.S. Hendricks and S.S. Talmage, 1989. Physicochemical properties as predictors of organic chemical effects on soil microbial respiration. *Environ. Toxicol. Chem.*, 8, 53-63.
- Wolf, M.A., V.K. Rowe, D.D. McCollister, R.L. Hollingsworth and F. Oyen, 1956. Toxicological studies of certain alkylated benzenes and benzene. *Arch. Ind. Health*, 14, 387-398. cited in U.S. EPA, 2000.

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Table 1.1. Chemical-Specific Data – BTEX and BaP

Parameter		Benzene	Toluene	Ethylbenzene	Xylenes	B(a)P
<i>Human Toxicity and Availability</i>						
Tolerable Daily Intake	TDI mg/kg-bw/day	NA	0.22 ^a	0.1 ^b	1.5 ^a	NA
Reference Concentration	RfC mg/m ³	NA	3.8 ^a	1 ^b	0.18 ^a	NA
Risk Specific Dose	RSD mg/kg-bw/day	0.00069 ^c	NA	NA	NA	0.0000014 ^b
Risk Specific Concentration	RSC mg/m ³	0.003 ^a	NA	NA	NA	0.00016 ^a
Gut Absorption Factor	AF _G unitless	1 ^j	1 ^j	1 ^j	1 ^j	1 ^j
Dermal Absorption Factor	AF _D unitless	0.08 ^k	0.12 ^k	0.2 ^k	0.12 ^k	0.2 ^k
<i>Human Background Exposure</i>						
Estimated Daily Intake	EDI mg/kg-bw/day	NA	0.0028 ^d	0.0029 ^e	0.0079 ^f	NA
Background Indoor Air Concentration	C _a mg/m ³	NA	0.0050 ^g	0.0075 ^g	0.00182 ^f	NA
Background Soil Concentration	BSC mg/kg	0 ^j	0 ^j	0 ^j	0 ^j	0 ^j
Soil Allocation Factor	SAF unitless	0.5 ^g	0.5 ^g	0.5 ^g	0.5 ^g	0.6 ^h
<i>Livestock/Wildlife Toxicity</i>						
Daily Threshold Effects Dose	DTED mg/kg-bw/day	0.08 ⁱ	4.46 ⁱ	2.91 ⁱ	11.9 ⁱ	NA
<i>Physical/Chemical/Degradation Parameters</i>						
Water Organic Carbon Partition Coefficient	K _{oc} mL/g	81.2 ^j	234 ^j	537 ^j	586 ^j	NA
Henry's Law Constant	H ^j unitless	0.225	0.274	0.358	0.252	NA
Decay Half-Life	t _{1/2} days	365 ^m	105 ^m	114 ^m	183 ^m	NA
Diffusion Coefficient in Air	D _a cm ² /s	0.088 ^l	0.087 ^l	0.075 ^l	0.078 ^l	NA
Solubility	S mg/L	1,780 ^l	515 ^l	152 ^l	198 ^l	0.0038 ^l

Notes:

NA = not applicable;

B(a)P = benzo(a)pyrene;

a. Health Canada (1996b

b. US EPA (2007);

10⁻⁵.

c. Based on the RSC. (RSD = RSC x 16.2 m³/day / 70.7 kg); i. See Appendix A for derivation of the DTED;

d. Health Canada (1992);

e. ATSDR (1999);

f. Health Canada (1993);

g. Soil allocation factor for PHC F1 (CCME, 2000); m. BCMELP (1996); and,

h. Soil allocation factor for PHC F3 (CCME, 2000); The RSD and RSC are based on an incremental cancer risk of 1 x

10⁻⁵.

j. assumed;

k. CCME (2000);

l. TPHCWG (1997);

Table 1.3. Chemical-Specific Data – PHC Fractions F1-F4

Parameter		F1	F2	F3	F4
Gut Absorption Factor	AF _G	1.0	1.0	1.0	1.0
Dermal Absorption Factor	AF _D	0.2	0.2	0.2	0.2
Background Soil Concentration	BSC	0	0	0	0
Soil Allocation Factor	SAF	0.5	0.5	0.6	0.8
Daily Threshold Effects Dose	DTED	9.74	8.95	14.5	9.64
Decay Half-Life	t _{1/2}	712	1,750	NA	NA
Diffusion Coefficient in Air	D _a	0.05	0.05	NA	NA

Notes:
all values from CCME (2000); and,
NA = not applicable.

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Table 2.1. Alberta Tier 1 Hydrocarbon Guidelines for Fine Surface Soil

Land Use	Exposure Pathway	Benzene (mg/kg)	Toluene (mg/kg)	Ethyl- benzene (mg/kg)	Xylenes (mg/kg)	B(a)P (mg/kg)	F1 (mg/kg)	F2 (mg/kg)	F3 (mg/kg)	F4 (mg/kg)
Natural Area	Protection of Potable Groundwater *	0.073	0.86	0.19	25	NA	1,900	2,600	NA	NA
	Soil Contact (Plants and Invertebrates)	14	300	450	1,200	F3	260	900	800	5,600
	Soil Ingestion (Wildlife)	93	5,200	3,400	14,000	F3	11,000	10,000	17,000	11,000
	Protection of Groundwater for Aquatic Life *	RES	RES	RES	RES	F3	TBD	TBD	NA	NA
	Protection of Groundwater for Wildlife *	RES	RES	RES	RES	F3	TBD	TBD	NA	NA
Agricultural	Human Soil Ingestion	1,200	22,000	10,000	RES	4.9	15,000	8,000	18,000	25,000
	Human Dermal Contact	2,700	RES	RES	RES	4.3	RES	RES	RES	RES
	Human Vapour Inhalation (basement) ¹	1.9	4,600	2,000	500	NA	940	5,200	NA	NA
	Human Vapour Inhalation (slab-on-grade) ¹	1.9	4,600	2,000	500	NA	940	5,200	NA	NA
	Protection of Potable Groundwater *	0.073	0.86	0.19	25	NA	1,900	2,600	NA	NA
Residential	Protection of Potable Groundwater *	14	300	450	1,200	F3	260	900	800	5,600
	Soil Ingestion (Livestock)	33	1,800	1,200	4,600	F3	4,000	3,700	6,000	4,000
	Protection of Groundwater for Aquatic Life *	RES	RES	RES	RES	F3	TBD	TBD	NA	NA
	Protection of Groundwater for Livestock	RES	RES	RES	RES	F3	TBD	TBD	NA	NA
	Human Soil Ingestion	1,200	22,000	10,000	RES	4.9	15,000	8,000	18,000	25,000
Commercial	Human Dermal Contact	2,700	RES	RES	RES	4.3	RES	RES	RES	RES
	Human Vapour Inhalation (basement)	1.9	4,600	2,000	500	NA	940	5,200	NA	NA
	Human Vapour Inhalation (slab-on-grade)	1.9	4,600	2,000	500	NA	940	5,200	NA	NA
	Protection of Potable Groundwater *	0.073	0.86	0.19	25	NA	1,900	2,600	NA	NA
	Soil Contact (Plants and Invertebrates)	14	300	450	1,200	F3	260	900	800	5,600
Industrial	Protection of Groundwater for Aquatic Life *	RES	RES	RES	RES	F3	TBD	TBD	NA	NA
	Human Soil Ingestion	4,400	RES	RES	RES	18	RES	29,000	RES	RES
	Human Dermal Contact	9,700	RES	RES	RES	16	RES	RES	RES	RES
	Human Vapour Inhalation	9	22,000	9,700	2,400	NA	4,600	25,000	NA	NA
	Protection of Potable Groundwater *	0.073	0.86	0.19	25	NA	1,900	2,600	NA	NA
Industrial	Soil Contact (Plants and Invertebrates)	38	450	690	1,500	F3	660	1,500	2,500	6,600
	Protection of Groundwater for Aquatic Life *	RES	RES	RES	RES	F3	TBD	TBD	NA	NA
	Human Soil Ingestion	4,400	RES	RES	RES	18	RES	RES	RES	RES
	Human Dermal Contact	9,700	RES	RES	RES	16	RES	RES	RES	RES
	Human Vapour Inhalation	9	22,000	9,700	2,400	NA	4,600	25,000	NA	NA
Industrial	Protection of Potable Groundwater *	0.073	0.86	0.19	25	NA	1,900	2,600	NA	NA
	Soil Contact (Plants and Invertebrates)	38	450	690	1,500	F3	660	1,500	2,500	6,600
	Protection of Groundwater for Aquatic Life *	RES	RES	RES	RES	F3	TBD	TBD	NA	NA
	Human Soil Ingestion	4,400	RES	RES	RES	18	RES	RES	RES	RES
	Human Dermal Contact	9,700	RES	RES	RES	16	RES	RES	RES	RES
Industrial	Human Vapour Inhalation	9	22,000	9,700	2,400	NA	4,600	25,000	NA	NA
	Protection of Potable Groundwater *	0.073	0.86	0.19	25	NA	1,900	2,600	NA	NA
	Soil Contact (Plants and Invertebrates)	38	450	690	1,500	F3	660	1,500	2,500	6,600
	Protection of Groundwater for Aquatic Life *	RES	RES	RES	RES	F3	TBD	TBD	NA	NA
	Human Soil Ingestion	4,400	RES	RES	RES	18	RES	RES	RES	RES

Guidelines apply for all substances. Pathways apply as per Sections 2.6, 4 and 5 of Volume 3 in this series.

Notes:

1. this pathway can be excluded within 15 m of an oilfield wellhead;

bold = lowest value for each chemical and land use;

underlined = PHC guidelines adopted without change from CCME (2000);

* the potable groundwater, aquatic life, and groundwater for wildlife

pathways may not apply at a given site: see text for details;

BaP = benzo(a)pyrene;

all values are presented to two significant figures

RES = calculated value exceeds 30,000 mg/kg;

NA = not applicable;

TBD = to be determined;

F3 = ecological endpoints for B(a)P are included in the guideline for F3; and, F1 to F4 = petroleum hydrocarbon fractions as defined by CCME (2000).

Table 2.2 Alberta Tier 1 Hydrocarbon Guidelines for Coarse Surface Soil

Land Use	Exposure Pathway	Benzene (mg/kg)	Toluene (mg/kg)	Ethyl- benzene (mg/kg)	Xylenes (mg/kg)	B(a)P (mg/kg)	F1 (mg/kg)	F2 (mg/kg)	F3 (mg/kg)	F4 (mg/kg)
Natural Area	Protection of Potable Groundwater *	0.13	1.6	0.36	49	NA	3,700	5,100	NA	NA
	Soil Contact (Plants and Invertebrates)	8.3	24	91	90	F3	130	450	400	2,800
	Soil Ingestion (Wildlife)	93	5,200	3,400	14,000	F3	11,000	10,000	17,000	11,000
	Protection of Groundwater for Aquatic Life *	1.6	0.16	79	59	F3	360	230	NA	NA
Agricultural	Protection of Groundwater for Wildlife *	5.3	5,400	RES	RES	F3	16,000	15,000	NA	NA
	Human Soil Ingestion	1,200	22,000	10,000	RES	4.9	15,000	8,000	18,000	25,000
	Human Dermal Contact	2,700	RES	RES	RES	4.3	RES	RES	RES	RES
	Human Vapour Inhalation (basement) ¹	0.077	200	88	22	NA	50	240	NA	NA
	Human Vapour Inhalation (slab-on-grade) ¹	0.048	120	54	14	NA	30	150	NA	NA
	Protection of Potable Groundwater *	0.13	1.6	0.36	49	F3	3,700	5,100	NA	NA
	Soil Contact (Plants and Invertebrates)	8.3	24	91	90	F3	130	450	400	2,800
	Soil Ingestion (Livestock)	33	1,800	1,200	4,900	F3	4,000	3,700	6,000	4,000
Residential	Protection of Groundwater for Aquatic Life *	1.6	0.16	79	59	F3	360	230	NA	NA
	Protection of Groundwater for Livestock	2.2	2,200	16,000	25,000	F3	11,000	8,600	NA	NA
	Human Soil Ingestion	1,200	22,000	10,000	RES	4.9	15,000	8,000	18,000	25,000
	Human Dermal Contact	2,700	RES	RES	RES	4.3	RES	RES	RES	RES
	Human Vapour Inhalation (basement)	0.077	200	88	22	NA	50	240	NA	NA
	Human Vapour Inhalation (slab-on-grade)	0.048	120	54	14	NA	30	150	NA	NA
	Protection of Potable Groundwater *	0.13	1.6	0.36	49	F3	3,700	5,100	NA	NA
	Soil Contact (Plants and Invertebrates)	8.3	24	91	90	F3	130	450	400	2,800
Commercial	Protection of Groundwater for Aquatic Life *	1.6	0.16	79	59	F3	360	230	NA	NA
	Human Soil Ingestion	4,400	RES	RES	RES	18	RES	29,000	RES	RES
	Human Dermal Contact	9,700	RES	RES	RES	16	RES	RES	RES	RES
	Human Vapour Inhalation	0.55	1,400	630	160	NA	310	1,700	NA	NA
	Protection of Potable Groundwater *	0.13	1.6	0.36	49	F3	3,700	5,100	NA	NA
	Soil Contact (Plants and Invertebrates)	13	71	200	130	F3	330	760	1,700	3,300
	Protection of Groundwater for Aquatic Life *	1.6	0.16	79	59	F3	360	230	NA	NA
Industrial	Human Soil Ingestion	4,400	RES	RES	RES	18	RES	RES	RES	RES
	Human Dermal Contact	9,700	RES	RES	RES	16	RES	RES	RES	RES
	Human Vapour Inhalation	0.55	1,400	630	160	NA	310	1,700	NA	NA
	Protection of Potable Groundwater *	0.13	1.6	0.36	49	NA	3,700	5,100	NA	NA
	Soil Contact (Plants and Invertebrates)	13	71	200	130	F3	330	760	1,700	3,300
	Protection of Groundwater for Aquatic Life *	1.6	0.16	79	59	F3	360	230	NA	NA

Guidelines apply for all substances. Pathways apply as per Sections 2.6, 4 and 5 of Volume 3 in this series.

Notes:

1. this pathway can be excluded within 15 m of an oilfield wellhead;

bold = lowest value for each chemical and land use;

underlined = PHC guidelines adopted without change from CCME (2000);

* the potable groundwater, aquatic life, and groundwater for wildlife

pathways may not apply at a given site: see text for details;

BaP = benzo(a)pyrene;

all values are presented to two significant figures

RES = calculated value exceeds 30,000 mg/kg;

NA = not applicable;

TBD = to be determined; and,

F3 = ecological endpoints for B(a)P are included in the guideline for F3; and,

F1 to F4 = petroleum hydrocarbon fractions as defined by CCME (2000).

Table 2.3. Alberta Hydrocarbon Guidelines for Fine Subsoil

Land Use	Exposure Pathway	Benzene (mg/kg)	Toluene (mg/kg)	Ethyl- benzene (mg/kg)	Xylenes (mg/kg)	B(a)P (mg/kg)	F1 (mg/kg)	F2 (mg/kg)	F3 (mg/kg)	F4 (mg/kg)
Natural Area ¹	Protection of Potable Groundwater *	0.073	0.86	0.19	25	NA	1,900	2,600	NA	NA
	Soil Contact (Plants and Invertebrates)	28	300	450	1,200	F3	750	2,200	3,500	10,000
	Soil Ingestion (Wildlife)	NA	NA	NA	NA	F3	TBD	NA	NA	NA
	Protection of Groundwater for Aquatic Life *	RES	RES	RES	RES	F3	TBD	TBD	NA	NA
Agricultural ¹	Protection of Groundwater for Wildlife *	RES	RES	RES	RES	F3	TBD	TBD	NA	NA
	Human Soil Ingestion	NA	NA	NA	NA	NA	RES	RES	RES	RES
	Human Dermal Contact	NA	NA	NA	NA	NA	RES	RES	RES	RES
	Human Vapour Inhalation (basement) ²	1.9	4,600	2,000	500	NA	940	5,200	NA	NA
	Human Vapour Inhalation (slab-on-grade) ²	1.9	4,800	2,100	520	NA	990	5,500	NA	NA
	Protection of Potable Groundwater *	0.073	0.86	0.19	25	NA	1,900	2,600	NA	NA
	Soil Contact (Plants and Invertebrates)	28	300	450	1,200	F3	750	2,200	3,500	10,000
	Soil Ingestion (Livestock)	RES	RES	RES	RES	F3	TBD	NA	NA	NA
Residential	Protection of Groundwater for Aquatic Life *	RES	RES	RES	RES	F3	TBD	TBD	NA	NA
	Protection of Groundwater for Livestock	RES	RES	RES	RES	F3	TBD	TBD	NA	NA
	Human Soil Ingestion	NA	NA	NA	NA	NA	RES	RES	RES	RES
	Human Dermal Contact	NA	NA	NA	NA	NA	RES	RES	RES	RES
	Human Vapour Inhalation (basement)	1.9	4,600	2,000	500	NA	940	5,200	NA	NA
	Human Vapour Inhalation (slab-on-grade)	1.9	4,800	2,100	520	NA	990	5,500	NA	NA
	Protection of Potable Groundwater *	0.073	0.86	0.19	25	NA	1,900	2,600	NA	NA
	Soil Contact (Plants and Invertebrates)	28	300	450	1,200	F3	750	2,200	3,500	10,000
Commercial	Protection of Groundwater for Aquatic Life *	RES	RES	RES	RES	F3	TBD	TBD	NA	NA
	Human Soil Ingestion	NA	NA	NA	NA	NA	RES	RES	RES	RES
	Human Dermal Contact	NA	NA	NA	NA	NA	RES	RES	RES	RES
	Human Vapour Inhalation	9	23,000	9,800	2,500	NA	4,800	26,000	NA	NA
	Protection of Potable Groundwater *	0.073	0.86	0.19	25	NA	1,900	2,600	NA	NA
	Soil Contact (Plants and Invertebrates)	77	450	690	1,500	F3	1,000	3,000	5,000	10,000
	Protection of Groundwater for Aquatic Life *	RES	RES	RES	RES	F3	TBD	TBD	NA	NA
	Human Soil Ingestion	NA	NA	NA	NA	NA	RES	RES	RES	RES
Industrial	Human Dermal Contact	NA	NA	NA	NA	NA	RES	RES	RES	RES
	Human Vapour Inhalation	9	23,000	9,800	2,500	NA	4,800	26,000	NA	NA
	Protection of Potable Groundwater *	0.073	0.86	0.19	25	NA	1,900	2,600	NA	NA
	Soil Contact (Plants and Invertebrates)	77	450	690	1,500	F3	1,000	3,000	5,000	10,000
	Protection of Groundwater for Aquatic Life *	RES	RES	RES	RES	F3	TBD	TBD	NA	NA
	Human Soil Ingestion	NA	NA	NA	NA	NA	RES	RES	RES	RES
	Human Dermal Contact	NA	NA	NA	NA	NA	RES	RES	RES	RES
	Human Vapour Inhalation	9	23,000	9,800	2,500	NA	4,800	26,000	NA	NA
	Protection of Potable Groundwater *	0.073	0.86	0.19	25	NA	1,900	2,600	NA	NA
	Soil Contact (Plants and Invertebrates)	77	450	690	1,500	F3	1,000	3,000	5,000	10,000
	Protection of Groundwater for Aquatic Life *	RES	RES	RES	RES	F3	TBD	TBD	NA	NA
	Human Soil Ingestion	NA	NA	NA	NA	NA	RES	RES	RES	RES

Guidelines apply for all substances. Pathways apply as per Sections 2.6, 4 and 5 of Volume 3 in this series.

Notes: 1. Subsoil guidelines are available at Tier 1 within 15 m of wellhead in natural area and agricultural; otherwise Tier 2B management is required.

2. This pathway can be excluded within 15 m of an oilfield wellhead;

bold = lowest value for each chemical and land use;

underlined = PHC guidelines adopted without change from CCME (2000);

* the potable groundwater, aquatic life, and groundwater for wildlife;

pathways may not apply at a given site; see text for details;

all values are presented to two significant figures

BaP = benzo(a)pyrene

F3 = ecological endpoints for B(a)P are included in F3; and,

F1 to F4 = petroleum hydrocarbon fractions defined by CCME (2000c)

TBD = to be determined; and

Table 2.4. Alberta Hydrocarbon Guidelines for Coarse Subsoil

Land Use	Exposure Pathway	Benzene (mg/kg)	Toluene (mg/kg)	Ethyl- benzene (mg/kg)	Xylenes (mg/kg)	B(a)P (mg/kg)	F1 (mg/kg)	F2 (mg/kg)	F3 (mg/kg)	F4 (mg/kg)
Natural Area ¹	Protection of Potable Groundwater *	0.13	1.6	0.36	49	NA	3,700	5,100	NA	NA
	Soil Contact (Plants and Invertebrates)	17	48	180	180	F3	350	1,500	2,500	10,000
	Soil Ingestion (Wildlife)	NA	NA	NA	NA	F3	NA	NA	NA	NA
	Protection of Groundwater for Aquatic Life *	1.6	0.16	79	59	F3	360	230	NA	NA
Agricultural ¹	Protection of Groundwater for Wildlife *	5.3	5,400	RES	RES	F3	16,000	15,000	NA	NA
	Human Soil Ingestion	NA	NA	NA	NA	NA	RES	RES	RES	RES
	Human Dermal Contact	NA	NA	NA	NA	NA	RES	RES	RES	RES
	Human Vapour Inhalation (basement) ²	0.077	200	88	22	NA	50	240	NA	NA
	Human Vapour Inhalation (slab-on-grade) ²	0.054	140	61	15	NA	40	190	NA	NA
	Protection of Potable Groundwater *	0.13	1.6	0.36	49	NA	3,700	5,100	NA	NA
	Soil Contact (Plants and Invertebrates)	17	48	180	180	F3	350	1,500	2,500	10,000
	Soil Ingestion (Livestock)	NA	NA	NA	NA	F3	NA	NA	NA	NA
	Protection of Groundwater for Aquatic Life *	1.6	0.16	79	59	F3	360	230	NA	NA
	Protection of Groundwater for Livestock	2.2	2,200	18,000	25,000	F3	11,000	8,600	NA	NA
Residential	Human Soil Ingestion	NA	NA	NA	NA	NA	RES	RES	RES	RES
	Human Dermal Contact	NA	NA	NA	NA	NA	RES	RES	RES	RES
	Human Vapour Inhalation (basement)	0.077	200	88	22	NA	50	240	NA	NA
	Human Vapour Inhalation (slab-on-grade)	0.054	140	61	15	NA	40	190	NA	NA
	Protection of Potable Groundwater *	0.13	1.6	0.36	49	NA	3,700	5,100	NA	NA
	Soil Contact (Plants and Invertebrates)	17	48	180	180	F3	350	1,500	2,500	10,000
Commercial	Protection of Groundwater for Aquatic Life *	1.6	0.16	79	59	F3	360	230	NA	NA
	Human Soil Ingestion	NA	NA	NA	NA	NA	RES	RES	RES	RES
	Human Dermal Contact	NA	NA	NA	NA	NA	RES	RES	RES	RES
	Human Vapour Inhalation	0.58	1,500	660	170	NA	340	1,800	NA	NA
	Protection of Potable Groundwater *	0.13	1.6	0.36	49	NA	3,700	5,100	NA	NA
	Soil Contact (Plants and Invertebrates)	25	140	390	260	F3	700	2,000	3,500	10,000
Industrial	Protection of Groundwater for Aquatic Life *	1.6	0.16	79	59	F3	360	230	NA	NA
	Human Soil Ingestion	NA	NA	NA	NA	NA	RES	RES	RES	RES
	Human Dermal Contact	NA	NA	NA	NA	NA	RES	RES	RES	RES
	Human Vapour Inhalation	0.58	1,500	660	170	NA	340	1,800	NA	NA
	Protection of Potable Groundwater *	0.13	1.6	0.36	49	NA	3,700	5,100	NA	NA
	Soil Contact (Plants and Invertebrates)	25	140	390	260	F3	700	2,000	3,500	10,000

Guidelines apply for all substances. Pathways apply as per Sections 2.6, 4 and 5 of Volume 3 in this series.

Notes: 1. subsoil guidelines are available at Tier 1 within 15 m of wellhead in natural area and agricultural; otherwise Tier 2B management is required.

2. this pathway can be excluded within 15 m of an oilfield wellhead;

bold = lowest value for each chemical and land use;

underlined = PHC guidelines adopted without change from CCME (2000);

* the potable groundwater, aquatic life, and groundwater for wildlife;

pathways may not apply at a given site: see text for details;

all values are presented to two significant figures

RES = calculated value exceeds 30,000 mg/kg;

NA = not applicable;

TBD = to be determined; and

BaP = benzo(a)pyrene

F3 = ecological endpoints for B(a)P are included in F3; and

F1 to F4 = petroleum hydrocarbon fractions defined by CCME (2000c)

F1 to F4 = petroleum hydrocarbon fractions as defined by CCME (2000).

Table 5.1. Exposure Point Water Quality Guidelines

Criteria	Benzene (mg/L)	Toluene (mg/L)	Ethylbenzene (mg/L)	Xylenes (mg/L)	F1 (mg/L)	F2 (mg/L)
Human Drinking Water	0.005 ⁽¹⁾	0.024 ⁽¹⁾	0.0024 ⁽¹⁾	0.3 ⁽¹⁾	4.6 ⁽²⁾	2.1 ⁽²⁾
Freshwater Aquatic Life	0.370 ⁽³⁾	0.002 ⁽³⁾	0.090 ⁽³⁾	0.180 ⁽⁴⁾	0.017 ⁽⁵⁾	0.00016 ⁽⁵⁾
Livestock Watering (Cattle)	0.51 ⁽⁶⁾	29 ⁽⁶⁾	19 ⁽⁶⁾	76 ⁽⁶⁾	62 ⁽⁷⁾	57 ⁽⁷⁾
Wildlife Watering	1.2 ⁽⁸⁾	69 ⁽⁸⁾	45 ⁽⁸⁾	180 ⁽⁸⁾	150 ⁽⁹⁾	140 ⁽⁹⁾

Notes:

1. Health Canada (1996);
2. derived for this project by combining TDIs for hydrocarbon sub-fractions (see text);
3. CCME (1999);
4. derived for this project (see Appendix I);
5. derived from combining values for TPHCWG (1996) sub-fractions in Scientific Rationale Document (CCME, 2000);
6. derived for this project using daily threshold effect dose and physico-chemical characteristics for dairy cow (see text);
7. from CCME (2000);
8. derived for this project using daily threshold effect dose and physico-chemical characteristics for deer (see text); and,
9. derived from dairy cow data in CCME (2000) and deer body weight and ingestion rate.

Table 5.2. Groundwater Quality Guidelines

Criteria	Benzene (mg/L)	Toluene (mg/L)	Ethylbenzene (mg/L)	Xylenes (mg/L)	B(a)P (mg/L)	F1 (mg/L)	F2 (mg/L)
All Soils							
Human Drinking Water	0.005	0.024	0.0024	0.3	0.00001	4.6	2.1
Livestock Watering	0.51	29	19	76	NA	62	57
All Soils; Piezometers <10 m from Surface Water Body							
Freshwater Aquatic Life	0.370	0.002	0.090	0.180	NA	ND	ND
Wildlife Watering	1.2	69	45	180	NA	150	140
Coarse Soils; Piezometers >10 m from Surface Water Body							
Freshwater Aquatic Life	0.53	0.021	4.8	3.3	NA	NG	NG
Wildlife Watering	1.8	NG	NG	NG	NA	NG	NG
Fine Soils; Piezometers >10 m from Surface Water Body							
Freshwater Aquatic Life	NG	NG	NG	NG	NA	NG	NG
Wildlife Watering	NG	NG	NG	NG	NA	NG	NG

Notes:

NG = no guideline required for this pathway – limited by solubility from ever exceeding surface water criterion at 10 m offset;

NA = not applicable;

ND = not determined, due to uncertainties with the critical body residue method of determining aquatic toxicity; and,

see Volume 2 of this project for further explanation of values in this table.

Table A-1. Combined IC50/LC50 Data – Alberta Till (Fine)

Species	Root/Shoot Parameter		IC50/EC50			
			Benzene (mg/kg)	Toluene (mg/kg)	Ethylbenzene (mg/kg)	Xylenes (mg/kg)
Northern Wheatgrass	Shoot	Length	41.0	957.9	2,495.0	3,498.6
	Shoot	Wet Mass	42.8	466.9	642.9	1,680.4
	Shoot	Dry Mass	35.9	424.2	728.7	1,386.6
	Root	Length	80.0	506.0	1,135.9	1,768.8
	Root	Wet Mass	9.4	219.9	308.1	1,371.8
	Root	Dry Mass	19.1	388.8	582.0	998.2
	Worm	Mortality	5.5	65.4	29.4	42.3
25 th Percentile of Plant and Invertebrate Data			14	302	445	1,185
50 th Percentile of Plant Data Only			38	446	686	1,533

Table A-2. Combined IC50/LC50 Data - Artificial Soil (Coarse)

Species	Root/Shoot	Parameter	IC50/LC50			
			Benzene (mg/kg)	Toluene (mg/kg)	Ethylbenzene (mg/kg)	Xylenes (mg/kg)
Northern Wheatgrass	Shoot	Length	35.0	517.6	1,047.4	564.3
	Shoot	Wet Mass	15.3	74.5	166.7	124.1
	Shoot	Dry Mass	7.7	68.5	212.2	134.5
	Root	Length	18.5	119.4	643.7	290.7
	Root	Wet Mass	10.1	19.3	15.5	65.4
	Root	Dry Mass	5.3	28.3	177.1	113.8
<i>Eisenia andrei</i>	Worm	Mortality	N/A	5.1	10.7	8.8
25 th Percentile of Plant and Invertebrate Data			8.3	24	91	90
50 th Percentile of Plant Data Only			13	71	195	129

Table A-3. Freshwater Aquatic Toxicity Data for Xylenes

Scientific Name	Common Name	Endpoint	Effect	Test Duration	Duration Units	Exposure Type	Concentration	Concentration Units	Author	Year	Title	Reference Source
<i>Daphnia magna</i>	Water flea	EC50	ITX	24	H	S	1,000	µg/L	GALASSI, S., M. MINGAZZINI, L. VIGANO, D. CESAREO, AND M.L. TOSATO	1988	Approaches to Modeling Toxic Responses of Aquatic Organisms to Aromatic Hydrocarbons	Ecotoxicol Environ Saf 16(2):158-169
<i>Daphnia magna</i>	Water flea	EC50	ITX	48	H	S	1,390	µg/L	MACLEAN, M.M. AND K.G. DOE	1989	The Comparative Toxicity of Crude and Refined Oils to <i>Daphnia magna</i> and <i>Artemia</i>	Environment Canada, Dartmouth, Nova Scoti a:64 EE-111,
<i>Daphnia magna</i>	Water flea	EC50	ITX	48	H	S	1,390	µg/L	MACLEAN, M.M. AND K.G. DOE	1989	The Comparative Toxicity of Crude and Refined Oils to <i>Daphnia magna</i> and <i>Artemia</i>	Environment Canada, Dartmouth, Nova Scoti a:64 EE-111,
<i>Daphnia magna</i>	Water flea	EC50	ITX	48	H	S	1,870	µg/L	MACLEAN, M.M. AND K.G. DOE	1989	The Comparative Toxicity of Crude and Refined Oils to <i>Daphnia magna</i> and <i>Artemia</i>	Environment Canada, Dartmouth, Nova Scoti a:64 EE-111,
<i>Oncorhynchus mykiss</i>	Rainbow trout, Donaldson trout	LC50	MOR	96	H	R	2,600	µg/L	GALASSI, S., M. MINGAZZINI, L. VIGANO, D. CESAREO, AND M.L. TOSATO	1988	Approaches to Modeling Toxic Responses of Aquatic Organisms to Aromatic Hydrocarbons	Ecotoxicol Environ Saf 16(2):158-169
<i>Daphnia magna</i>	Water flea	EC50	ITX	48	H	S	3,186	µg/L	BOBRA, A.M., W.Y. SHIU, AND D. MACKAY	1983	A Predictive Correlation for the Acute Toxicity of Hydrocarbons and Chlorinated Hydrocarbons to the Water Flea (<i>Daphnia magna</i>)	Chemosphere 12(9-10):1121-1129

Table A-3. Freshwater Aquatic Toxicity Data for Xylenes (Continued)

Scientific Name	Common Name	Endpoint	Effect	Test Duration	Duration Units	Exposure Type	Concentration	Concentration Units	Author	Year	Title	Reference Source
<i>Selenastrum capricornutum</i>	Green algae	EC50	GRO	72	H	S	3,200	µg/L	GALASSI, S., M. MINGAZZINI, L. VIGANO, D. CESAREO, AND M.L. TOSATO	1988	Approaches to Modeling Toxic Responses of Aquatic Organisms to Aromatic Hydrocarbons	Ecotoxicol Environ Saf 16(2):158-169
<i>Daphnia magna</i>	Water flea	EC50	ITX	48	H	S	3,530	µg/L	MACLEAN, M.M. AND K.G. DOE	1989	The Comparative Toxicity of Crude and Refined Oils to <i>Daphnia magna</i> and <i>Artemia</i>	Environment Canada, EE-111, Dartmouth, Nova Scotia:64
<i>Daphnia magna</i>	Water flea	EC50	ITX	24	H	S	3,600	µg/L	GALASSI, S., M. MINGAZZINI, L. VIGANO, D. CESAREO, AND M.L. TOSATO	1988	Approaches to Modeling Toxic Responses of Aquatic Organisms to Aromatic Hydrocarbons	Ecotoxicol Environ Saf 16(2):158-169
<i>Daphnia magna</i>	Water flea	EC50	ITX	48	H	F	3,820	µg/L	HOLCOMBE, G.W., G.L. PHIPPS, A.H. SULAIMAN, AND A.D. HOFFMAN	1987	Simultaneous Multiple Species Testing: Acute Toxicity of 13 Chemicals to 12 Diverse Freshwater Amphibian, Fish, and Invertebrate Families	Arch Environ Contam Toxicol 16:697-710
<i>Selenastrum capricornutum</i>	Green algae	EC50	GRO	8	D	S	3,900	µg/L	HERMAN, D.C., W.E. INNIS, AND C.I. MAYFIELD	1990	Impact of Volatile Aromatic Hydrocarbons, Alone and in Combination, on Growth of the Freshwater Alga <i>Selenastrum capricornutum</i>	Aquat Toxicol 18(2):87-100

Table A-3. Freshwater Aquatic Toxicity Data for Xylenes (Continued)

Scientific Name	Common Name	Endpoint	Effect	Test Duration	Duration Units	Exposure Type	Concentration	Concentration Units	Author	Year	Title	Reference Source
<i>Selenastrum capricornutum</i>	Green algae	EC50	GRO	8	D	S	4,200	µg/L	HERMAN, D.C., INNISS, AND MAYFIELD	1990	Impact of Volatile Aromatic Hydrocarbons, Alone and in Combination, on Growth of the Freshwater Alga <i>Selenastrum capricornutum</i>	Aquat Toxicol 18(2):87-100
<i>Selenastrum capricornutum</i>	Green algae	EC50	GRO	8	D	S	4,400	µg/L	HERMAN, D.C., INNISS, AND MAYFIELD	1990	Impact of Volatile Aromatic Hydrocarbons, Alone and in Combination, on Growth of the Freshwater Alga <i>Selenastrum capricornutum</i>	Aquat Toxicol 18(2):87-100
<i>Selenastrum capricornutum</i>	Green algae	EC50	GRO	72	H	S	4,700	µg/L	GALASSI, S., M. MINGAZZINI, L. VIGANO, D. CESAREO, AND M.L. TOSATO	1988	Approaches to Modeling Toxic Responses of Aquatic Organisms to Aromatic Hydrocarbons	Ecotoxicol Environ Saf 16(2):158-169
<i>Daphnia magna</i>	Water flea	EC50	ITX	24	H	S	4,700	µg/L	GALASSI, S., M. MINGAZZINI, L. VIGANO, D. CESAREO, AND M.L. TOSATO	1988	Approaches to Modeling Toxic Responses of Aquatic Organisms to Aromatic Hydrocarbons	Ecotoxicol Environ Saf 16(2):158-169
<i>Daphnia magna</i>	Water flea	EC50	ITX	48	H	S	4,730	µg/L	MACLEAN, M.M. AND K.G. DOE	1989	The Comparative Toxicity of Crude and Refined Oils to <i>Daphnia magna</i> and <i>Artemia</i>	Environment Canada, EE-111, Dartmouth, Nova Scoti a:64

Table A-3. Freshwater Aquatic Toxicity Data for Xylenes (Continued)

Scientific Name	Common Name	Endpoint	Effect	Test Duration	Duration Units	Exposure Type	Concentration	Concentration Units	Author	Year	Title	Reference Source
<i>Selenastrum capricornutum</i>	Green algae	EC50	GRO	72	H	S	4,900	µg/L	GALASSI, S., M. MINGAZZINI, L. VIGANO, D. CESAREO, AND M.L. TOSATO	1988	Approaches to Modeling Toxic Responses of Aquatic Organisms to Aromatic Hydrocarbons	Ecotoxicol Environ Saf 16(2):158-169
<i>Daphnia magna</i>	Water flea	EC50	ITX	48	H	S	5,000	µg/L	MACLEAN, M.M. AND K.G. DOE	1989	The Comparative Toxicity of Crude and Refined Oils to <i>Daphnia magna</i> and <i>Artemia</i>	Environment Canada, Dartmouth, Nova Scoti a:64 EE-111,
<i>Daphnia magna</i>	Water flea	EC50	ITX	48	H	S	5,030	µg/L	MACLEAN, M.M. AND K.G. DOE	1989	The Comparative Toxicity of Crude and Refined Oils to <i>Daphnia magna</i> and <i>Artemia</i>	Environment Canada, Dartmouth, Nova Scoti a:64 EE-111,
<i>Artemia</i>	Brine shrimp	EC50	ITX	48	H	S	5,770	µg/L	MACLEAN, M.M. AND K.G. DOE	1989	The Comparative Toxicity of Crude and Refined Oils to <i>Daphnia magna</i> and <i>Artemia</i>	Environment Canada, Dartmouth, Nova Scoti a:64 EE-111,
<i>Artemia</i>	Brine shrimp	EC50	ITX	48	H	S	7,090	µg/L	MACLEAN, M.M. AND K.G. DOE	1989	The Comparative Toxicity of Crude and Refined Oils to <i>Daphnia magna</i> and <i>Artemia</i>	Environment Canada, Dartmouth, Nova Scoti a:64 EE-111,
<i>Oncorhynchus mykiss</i>	Rainbow trout, Donaldson trout	LC50	MOR	96	H	R	7,600	µg/L	GALASSI, S., M. MINGAZZINI, L. VIGANO, D. CESAREO, AND M.L. TOSATO	1988	Approaches to Modeling Toxic Responses of Aquatic Organisms to Aromatic Hydrocarbons	Ecotoxicol Environ Saf 16(2):158-169

Table A-3. Freshwater Aquatic Toxicity Data for Xylenes (Continued)

Scientific Name	Common Name	Endpoint	Effect	Test Duration	Duration Units	Exposure Type	Concentration	Concentration Units	Author	Year	Title	Reference Source
<i>Oncorhynchus mykiss</i>	Rainbow trout, Donaldson trout	LC50	MOR	96	H	F	8,050	µg/L	HOLCOMBE, G.W., G.L. PHIPPS, A.H. SULAIMAN, AND A.D. HOFFMAN	1987	Simultaneous Multiple Species Testing: Acute Toxicity of 13 Chemicals to 12 Diverse Freshwater Amphibian, Fish, and Invertebrate Families	Arch Environ Contam Toxicol 16:697-710
<i>Oncorhynchus mykiss</i>	Rainbow trout, Donaldson trout	LC50	MOR	96	H	R	8,400	µg/L	GALASSI, S., M. MINGAZZINI, L. VIGANO, D. CESAREO, AND M.L. TOSATO	1988	Approaches to Modeling Toxic Responses of Aquatic Organisms to Aromatic Hydrocarbons	Ecotoxicol Environ Saf 16(2):158-169
<i>Daphnia magna</i>	Water flea	EC50	ITX	48	H	S	8,496	µg/L	BOBBA, A.M., W.Y. SHIU, AND D. MACKEY	1983	A Predictive Correlation for the Acute Toxicity of Hydrocarbons and Chlorinated Hydrocarbons to the Water Flea (<i>Daphnia magna</i>)	Chemosphere 12(9-10):1121-1129
<i>Artemia</i>	Brine shrimp	LC50	MOR	48	H	S	8,520	µg/L	MACLEAN, M.M. AND K.G. DOE	1989	The Comparative Toxicity of Crude and Refined Oils to <i>Daphnia magna</i> and <i>Artemia</i>	Environment Canada, Dartmouth, Nova Scotia: 64 EE-111.
<i>Artemia</i>	Brine shrimp	EC50	ITX	48	H	S	8,540	µg/L	MACLEAN, M.M. AND K.G. DOE	1989	The Comparative Toxicity of Crude and Refined Oils to <i>Daphnia magna</i> and <i>Artemia</i>	Environment Canada, Dartmouth, Nova Scotia: 64 EE-111.

Table A-3. Freshwater Aquatic Toxicity Data for Xylenes (Continued)

Scientific Name	Common Name	Endpoint	Effect	Test Duration	Duration Units	Exposure Type	Concentration	Concentration Units	Author	Year	Title	Reference Source
<i>Poecilia reticulata</i>	Guppy	LC50	MOR	96	H	R	8,800	µg/L	GALASSI, S., M. MINGAZZINI, L. VIGANO, D. CESAREO, AND M.L. TOSATO	1988	Approaches to Modeling Toxic Responses of Aquatic Organisms to Aromatic Hydrocarbons	Ecotoxicol Environ Saf 16(2):158-169
<i>Artemia</i>	Brine shrimp	LC50	MOR	48	H	S	8,840	µg/L	MACLEAN, M.M. AND K.G. DOE	1989	The Comparative Toxicity of Crude and Refined Oils to <i>Daphnia magna</i> and <i>Artemia</i>	Environment Canada, Dartmouth, Nova Scoti a:64 EE-111.
<i>Daphnia magna</i>	Water flea	EC50	ITX	48	H	S	9,558	µg/L	BOBRA, A.M., W.Y. SHIU, AND D. MACKAY	1983	A Predictive Correlation for the Acute Toxicity of Hydrocarbons and Chlorinated Hydrocarbons to the Water Flea (<i>Daphnia magna</i>)	Chemosphere 12(9-10):1121-1129
<i>Artemia</i>	Brine shrimp	EC50	ITX	48	H	S	10,700	µg/L	MACLEAN, M.M. AND K.G. DOE	1989	The Comparative Toxicity of Crude and Refined Oils to <i>Daphnia magna</i> and <i>Artemia</i>	Environment Canada, Dartmouth, Nova Scoti a:64 EE-111.
<i>Artemia</i>	Brine shrimp	EC50	ITX	48	H	S	10,900	µg/L	MACLEAN, M.M. AND K.G. DOE	1989	The Comparative Toxicity of Crude and Refined Oils to <i>Daphnia magna</i> and <i>Artemia</i>	Environment Canada, Dartmouth, Nova Scoti a:64 EE-111.
<i>Poecilia reticulata</i>	Guppy	LC50	MOR	96	H	R	12,000	µg/L	GALASSI, S., M. MINGAZZINI, L. VIGANO, D. CESAREO, AND M.L. TOSATO	1988	Approaches to Modeling Toxic Responses of Aquatic Organisms to Aromatic Hydrocarbons	Ecotoxicol Environ Saf 16(2):158-169

Table A-3. Freshwater Aquatic Toxicity Data for Xylenes (Continued)

Scientific Name	Common Name	Endpoint	Effect	Test Duration	Duration Units	Exposure Type	Concentration	Concentration Units	Author	Year	Title	Reference Source
<i>Artemia</i>	Brine shrimp	LC50	MOR	48	H	S	12,200	µg/L	MACLEAN, M.M. AND K.G. DOE	1989	The Comparative Toxicity of Crude and Refined Oils to <i>Daphnia magna</i> and <i>Artemia</i>	Environment Canada, EE-111, Dartmouth, Nova Scoti a:64
<i>Artemia</i>	Brine shrimp	EC50	ITX	48	H	S	12,700	µg/L	MACLEAN, M.M. AND K.G. DOE	1989	The Comparative Toxicity of Crude and Refined Oils to <i>Daphnia magna</i> and <i>Artemia</i>	Environment Canada, EE-111, Dartmouth, Nova Scoti a:64
<i>Poecilia reticulata</i>	Guppy	LC50	MOR	96	H	R	12,900	µg/L	GALASSI, S., M. MINGAZZINI, L. VIGANO, D. CESAREO AND M.L. TOSATO	1988	Approaches to Modeling Toxic Responses of Aquatic Organisms to Aromatic Hydrocarbons	Ecotoxicol Environ Saf 16(2):158-169
<i>Carassius auratus</i>	Goldfish	LC50	MOR	24	H	S	13,000	µg/L	BRIDIE, A.L., C.J.M. WOLFF AND M. WINTER	1979	The Acute Toxicity of Some Petrochemicals to Goldfish	Water Res 13(7):623-626
<i>Artemia</i>	Brine shrimp	LC50	MOR	48	H	S	14,800	µg/L	MACLEAN, M.M. AND K.G. DOE	1989	The Comparative Toxicity of Crude and Refined Oils to <i>Daphnia magna</i> and <i>Artemia</i>	Environment Canada, EE-111, Dartmouth, Nova Scoti a:64
<i>Daphnia magna</i>	Water flea	LC50	MOR	48	H	S	15,700	µg/L	MACLEAN, M.M. AND K.G. DOE	1989	The Comparative Toxicity of Crude and Refined Oils to <i>Daphnia magna</i> and <i>Artemia</i>	Environment Canada, EE-111, Dartmouth, Nova Scoti a:64
<i>Carassius auratus</i>	Goldfish	LC50	MOR	24	H	S	16,000	µg/L	BRIDIE, A.L., C.J.M. WOLFF, AND M. WINTER	1979	The Acute Toxicity of Some Petrochemicals to Goldfish	Water Res 13(7):623-626

Table A-3. Freshwater Aquatic Toxicity Data for Xylenes (Continued)

Scientific Name	Common Name	Endpoint	Effect	Test Duration	Duration Units	Exposure Type	Concentration	Concentration Units	Author	Year	Title	Reference Source
<i>Pimephales promelas</i>	Fathead minnow	LC50	MOR	96	H	F	16,000	µg/L	GEIGER, D.L., L.T. BROOKE, AND D.J. CALL	1990	Acute Toxicities of Organic Chemicals to Fathead Minnows (Pimephales promelas), Vol. 5	Center for Lake Superior Environmental Studies, University of Wisconsin, Superior, WI:332
<i>Carassius auratus</i>	Goldfish	LC50	MOR	96	H	F	16,100	µg/L	HOLCOMBE, G.W., G.L. PHIPPS, A.H. SULAIMAN, AND A.D. HOFFMAN	1987	Simultaneous Multiple Species Testing: Acute Toxicity of 13 Chemicals to 12 Diverse Freshwater Amphibian, Fish, and Invertebrate Families	Arch Environ Contam Toxicol 16:697-710
<i>Catostomus commersoni</i>	White sucker	LC50	MOR	96	H	F	16,100	µg/L	HOLCOMBE, G.W., G.L. PHIPPS, A.H. SULAIMAN, AND A.D. HOFFMAN	1987	Simultaneous Multiple Species Testing: Acute Toxicity of 13 Chemicals to 12 Diverse Freshwater Amphibian, Fish, and Invertebrate Families	Arch Environ Contam Toxicol 16:697-710
<i>Lepomis macrochirus</i>	Bluegill	LC50	MOR	96	H	F	16,100	µg/L	HOLCOMBE, G.W., G.L. PHIPPS, A.H. SULAIMAN, AND A.D. HOFFMAN	1987	Simultaneous Multiple Species Testing: Acute Toxicity of 13 Chemicals to 12 Diverse Freshwater Amphibian, Fish, and Invertebrate Families	Arch Environ Contam Toxicol 16:697-710

Table A-3. Freshwater Aquatic Toxicity Data for Xylenes (Continued)

Scientific Name	Common Name	Endpoint	Effect	Test Duration	Duration Units	Exposure Type	Concentration	Concentration Units	Author	Year	Title	Reference Source
<i>Pimephales promelas</i>	Fathead minnow	LC50	MOR	96	H	F	16,100	µg/L	HOLCOMBE, G.W., G.L. PHIPPS, A.H. SULAIMAN, AND A.D. HOFFMAN	1987	Simultaneous Multiple Species Testing: Acute Toxicity of 13 Chemicals to 12 Diverse Freshwater Amphibian, Fish, and Invertebrate Families	Arch Environ Contam Toxicol 16:697-710
<i>Pimephales promelas</i>	Fathead minnow	LC50	MOR	96	H	F	16,400	µg/L	GEIGER, D.L., L.T. BROOKE, AND D.J. CALL	1990	Acute Toxicities of Organic Chemicals to Fathead Minnows (<i>Pimephales promelas</i>), Vol. 5	Center for Lake Superior Environmental Studies, University of Wisconsin, Superior, WI:332
<i>Pimephales promelas</i>	Fathead minnow	LC50	MOR	96	H	F	16,400	µg/L	GEIGER, D.L., L.T. BROOKE, AND D.J. CALL	1990	Acute Toxicities of Organic Chemicals to Fathead Minnows (<i>Pimephales promelas</i>), Vol. 5	Center for Lake Superior Environmental Studies, University of Wisconsin, Superior, WI:332
<i>Artemia</i>	Brine shrimp	EC50	ITX	24	H	S	16,500	µg/L	MACLEAN, M.M. AND K.G. DOE	1989	The Comparative Toxicity of Crude and Refined Oils to <i>Daphnia magna</i> and <i>Artemia</i>	Environment Canada, Dartmouth, Nova Scotia:64
<i>Daphnia magna</i>	Water flea	LC50	MOR	48	H	S	17,200	µg/L	MACLEAN, M.M. AND K.G. DOE	1989	The Comparative Toxicity of Crude and Refined Oils to <i>Daphnia magna</i> and <i>Artemia</i>	Environment Canada, Dartmouth, Nova Scotia:64
<i>Carassius auratus</i>	Goldfish	LC50	MOR	24	H	S	18,000	µg/L	BRIDIE, A.L., C.J.M. WOLFF, AND M. WINTER	1979	The Acute Toxicity of Some Petrochemicals to Goldfish	Water Res 13(7):623-626

Table A-3. Freshwater Aquatic Toxicity Data for Xylenes (Continued)

Scientific Name	Common Name	Endpoint	Effect	Test Duration	Duration Units	Exposure Type	Concentration	Concentration Units	Author	Year	Title	Reference Source
<i>Daphnia magna</i>	Water flea	LC50	MOR	48	H	S	19,600	µg/L	MACLEAN, M.M. AND K.G. DOE	1989	The Comparative Toxicity of Crude and Refined Oils to <i>Daphnia magna</i> and <i>Artemia</i>	Environment Canada, Dartmouth, Nova Scoti a:64 EE-111,
<i>Artemia</i>	Brine shrimp	EC50	ITX	24	H	S	20,600	µg/L	MACLEAN, M.M. AND K.G. DOE	1989	The Comparative Toxicity of Crude and Refined Oils to <i>Daphnia magna</i> and <i>Artemia</i>	Environment Canada, Dartmouth, Nova Scoti a:64 EE-111,
<i>Aplexa hypnorum</i>	Snail	LC50	MOR	96	H	F	22,400	µg/L	HOLCOMBE, G.W. G.L. PHIPPS, A.H. SULAIMAN, AND AD HOFFMAN	1987	Simultaneous Multiple Species Testing: Acute Toxicity of Chemicals to 12 Diverse Freshwater Amphibian, Fish, and Invertebrate Families	Arch Environ Contam Toxicol 16:697-
<i>Daphnia magna</i>	Water flea	LC50	MOR	48	H	S	23,600	µg/L	MACLEAN, M.M. AND K.G. DOE	1989	The Comparative Toxicity of Crude and Refined Oils to <i>Daphnia magna</i> and <i>Artemia</i>	Environment Canada, Dartmouth, Nova Scoti a:64 EE-111,
<i>Daphnia magna</i>	Water flea	LC50	MOR	48	H	S	28,000	µg/L	MACLEAN, M.M. AND K.G. DOE	1989	The Comparative Toxicity of Crude and Refined Oils to <i>Daphnia magna</i> and <i>Artemia</i>	Environment Canada, Dartmouth, Nova Scoti a:64 EE-111,
<i>Daphnia magna</i>	Water flea	LC50	MOR	48	H	S	31,500	µg/L	MACLEAN, M.M. AND K.G. DOE	1989	The Comparative Toxicity of Crude and Refined Oils to <i>Daphnia magna</i> and <i>Artemia</i>	Environment Canada, Dartmouth, Nova Scoti a:64 EE-111,

Table A-3. Freshwater Aquatic Toxicity Data for Xylenes (Continued)

Scientific Name	Common Name	Endpoint	Effect	Test Duration	Duration Units	Exposure Type	Concentration	Concentration Units	Author	Year	Title	Reference Source
<i>Daphnia magna</i>	Water flea	LC50	MOR	48	H	S	33,100	µg/L	MACLEAN, M.M. AND K.G. DOE	1989	The Comparative Toxicity of Crude and Refined Oils to <i>Daphnia magna</i> and <i>Artemia</i>	Environment Canada, Dartmouth, Nova Scotia: 64 EE-111,
<i>Daphnia magna</i>	Water flea	LC50	MOR	48	H	S	37,000	µg/L	MACLEAN, M.M. AND K.G. DOE	1989	The Comparative Toxicity of Crude and Refined Oils to <i>Daphnia magna</i> and <i>Artemia</i>	Environment Canada, Dartmouth, Nova Scotia: 64 EE-111,
<i>Chlorella vulgaris</i>	Green algae	EC50	GRO	24	H	S	55,000	µg/L	KAUSS, P.B. AND T.C. HUTCHINSON	1975	The Effects of Water-Soluble Petroleum Components on the Growth of <i>Chlorella vulgaris</i> Beijerinck	Environ Pollut 9(3):157-174
<i>Daphnia magna</i>	Water flea	LC50	MOR	48	H	S	55,700	µg/L	MACLEAN, M.M. AND K.G. DOE	1989	The Comparative Toxicity of Crude and Refined Oils to <i>Daphnia magna</i> and <i>Artemia</i>	Environment Canada, Dartmouth, Nova Scotia: 64 EE-111,
<i>Xenopus laevis</i>	Clawed toad	LC50	MOR	48	H	S	73,000	µg/L	DE ZWART, D. AND W. SLOOFF	1987	Toxicity of Mixtures of Heavy Metals and Petrochemicals to <i>Xenopus laevis</i>	Bull Environ Contam Toxicol 38(2):345-351
<i>Tetrahymena pyriformis</i>	Ciliate	IC50	POP	2	D	NR	88,100	µg/L	SCHULTZ, T.W., S.E. BRYANT, AND T.S. KISSEL	1996	Toxicological Assessment in <i>Tetrahymena</i> of Intermediates in Aerobic Microbial Transformation of Toluene and p-Xylene	Environ Contam Toxicol 56(1):129-134

NOTES:

Effect: GRO = growth; ITX = immobilization; MOR = mortality; POP = population growth.

Exposure Type: F = flow-through; R = renewal; S = static.

Table A-4. Reduced Freshwater Aquatic Toxicity Dataset for Xylenes

Species	Endpoint	Effect ⁽¹⁾	Duration (hours)	Number of Data Points ⁽²⁾	Concentration ⁽²⁾ (µg/L)
<i>Daphnia magna</i>	EC50	ITX	48	11	3,643
<i>Selenastrum capricornutum</i>	EC50	GRO	192	3	4,162
<i>Oncorhynchus mykiss</i>	LC50	MOR	96	4	6,046
<i>Poecilia reticulata</i>	LC50	MOR	96	3	11,085
<i>Carassius auratus</i>	LC50	MOR	96	1	16,100
<i>Catostomus commersoni</i>	LC50	MOR	96	1	16,100
<i>Lepomis macrochirus</i>	LC50	MOR	96	1	16,100
<i>Pimephales promelas</i>	LC50	MOR	96	4	16,224
<i>Aplexa hypnorum</i>	LC50	MOR	96	1	22,400
<i>Daphnia magna</i>	LC50	MOR	48	9	26,956
<i>Chlorella vulgaris</i>	EC50	GRO	24	1	55,000
<i>Xenopus laevis</i>	LC50	MOR	48	1	73,000
<i>Tetrahymena pyriformis</i>	IC50	POP	48	1	88,100

Notes:

10. Effect: GRO = growth; ITX = immobilization; MOR = mortality; POP = population growth and,
11. Where more than one data point is available, the concentration presented is the geometric mean.

